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REPORT

OF THE

PLANNING COMMITTEE FOR GEOPHYSICS

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REPORT OF THE PLANNING COMMITTEE FOR GEOPHYSICS

I.—APPOINTMENT OF THE PLANNING COMMITTEE.

1.1. With a view to clarify ideas regarding the development of geophysical work in India in the post-war period, and plan the geophysical work of the India Meteorological Department in co-ordination with the geophysical work of other Government Departments, like the Survey of India and the Geological Survey and of Universities and other Research Institutions, the Director General of Observatories, after a preliminary discussion with officers of the Survey of India and of the Geological Department, proposed to Government in December 1945 the setting up of a Planning Committee for Geophysics with representatives of the Survey of India, the Geological Survey, the India Meteorological Department and other interested Departments of Government.

1.2. The Government of India, Posts and Air Department, in their letter No. 18-M/10-45 dated New Delhi, the 21st January 1946, constituted a Committee consisting of the following members " to consider and report on the question of organising and developing in India institutions dealing with the study of Geophysics. "

(1) Prof. M. N. Saha, F.R.S., Council of Scientific and Industrial Research.

(2) Dr. J. de Graaff Hunter, C.I.E., Sc. D., F.R.S., Survey of India.

(3) Brigadier E. A. Glennie, C.I.E., D.S.O., Survey of India.

(4) Mr. D. N. Wadia, M.A., F.N.I., Adviser on Mineral Development, Department of Works, Mines and Power.

(5) Dr. W. D. West, Sc.D. (Cantab.), F.N.I., Geological Survey of India.

(6) Dr. G. Dessau, D.Ing. (Mining), Geological Survey of India.

(7) Dr. S. K. Banerji, O.B.E., D.Sc., F.N.I., India Meteorological Department.

(8) Dr. K. R. Ramanathan, M.A., D.Sc., F.N.I., India Meteorological Department.

The Director General of Observatories was authorised to convene such meetings as were required for the purpose. At the first meeting of the Committee which was held at Calcutta on the 4th and 5th February 1946, the Committee elected Professor M. N. Saha as its Chairman. In amplification of the Government's directive, the Committee decided that it should—

(1) prepare a plan for geophysical work in India making full use of the existing institutions, expanding them wherever necessary,

(2) define the fields of responsibility of different departments and institutions and suggest methods of co-ordinating the work as a whole,

(3) prepare plans for a Central Geophysical Institute,

(4) work out the requirements as regards finance and personnel, whichever is necessary.

In view of the importance of Hydrology as a branch of Geophysics, the Committee recommended that representatives of the Central Board of Irrigation or similar bodies should be invited to be members of the Committee. Accordingly the Government nominated *Rai Bahadur A. N. Khosla*, Chairman of the Central Waterways, Irrigation and Navigation Commission and *Mr. N. D. Gulhati*, Secretary to the Central Board of Irrigation, to be members. Brigadier Glennie left India on leave in March 1946, and his place was taken by *Mr. B. L. Gulatee*, Mathematical Adviser to the Survey of India. Dr. Graaff Hunter retired in April 1946 and *Col. J. B. P. Angwin*, Deputy Surveyor General, was appointed a member. For the last meeting, Col. Angwin's place was taken by *Col. C. A. K. Wilson*.

1.3. The Committee held seven meetings in all, one at Calcutta on the 4th and 5th February 1946, the second at New Delhi on the 25th March, the third at Bombay on the 2nd September, the fourth, fifth and sixth at New Delhi on the 25th November 1946, the 9th January 1947 and 10th March 1947 respectively and the seventh at Simla on 11th and 12th June 1947. Considerable work was also done by informal discussion between members. The Committee in their deliberations considered both the scientific and economic aspects of different branches of Geophysics, and after reviewing the present position of their development in this country, made recommendations on the lines on which they should be further developed.

II.—PROVINCE OF GEOPHYSICS—OR THE PHYSICS OF THE EARTH.

2.1. Geophysics is the study by physical methods of the earth on which we live—land, water and air. Methods have been developed by experimental physicists for the precise measurement of the physical properties of substances and of the phenomena taking place around us. Theoretical physicists have developed methods for the analysis and interpretation of fields of force due to bodies of varying shapes, sizes and dispositions—fields of gravitational attraction, of magnetic force, electric force, etc. Artificial disturbances can be created in the earth's crust as by the explosion of dynamite, and their effects studied. Geophysics is "a middle-ground science, since it shades off imperceptibly in one direction or another into the fields of Physics, Astronomy, Geology, to say nothing of Biology with which the subject of Oceanography is closely connected. Some branches of Geophysics such as Meteorology, Terrestrial Magnetism, Geodesy and Oceanography have long had a more or less independent existence.......For various reasons, among which may be mentioned the development of geophysical methods in prospecting for oil and minerals, there has lately been a considerable development of interest in Geophysics". Geophysical prospecting has emphasized the interdependence of the various branches and the necessity of considering Geophysics as an integrated Earth Science.

For the purposes of the Committee, Geophysics was taken to include :—

(i) Geodesy including measurements of gravity,

(ii) Seismology and Tectonophysics,

(iii) Terrestrial Magnetism and Earth Currents,

(iv) Geophysical Prospecting,

(v) Meteorology including Atmospheric Electricity,

(vi) Hydrology, and

(vii) Oceanography.

A statement summarising the scope of each of these sciences adapted from a note prepared by Dr. J. A. Fleming of the Carnegie Institution of Washington for the American Man-Power Commission is given below.

2.2. Geodesy deals with the mapping of the Earth and its configuration, the study of the effect on latitudes of the wobble of the Earth's axis, and the general and local variations of gravity. Geodesists triangulate the surface of the Earth for making maps, and run accurate levels to establish what are called bench-marks which are points of known elevation in order that the elevations of the various points of the Earth may be determined for railways, highways, streets, sewers and its many other modern needed improvements. Sensitive balances and pendulums and other means are used to determine the variations in the pull of gravity. A plumb-bob does not always point directly towards the centre of the Earth, but may be pulled somewhat to one side by the proximity of a mountain range, or by a deposition of heavy body of ore. The accurate determination of the variation in the pull of the Earth is very important to the geophysical prospector as it provides a means for studying the distribution of density in the Earth's interior without actually seeing it. Geodesy is thus very important to all the other branches of Geophysics which utilise in their daily work the knowledge which Geodesy provides.

2.3. Seismology is the study of earthquakes. Earthquakes are caused by breaks and movements in the crust of the Earth. The quake or wave travels both through and around the Earth. It gets reflected or refracted at internal surfaces of discontinuity. Through the study of past earthquakes, considerable knowledge has been gained of the way in which these waves travel and of the internal structure of the Earth. By means of delicate instruments called seismographs, it is possible to locate the source of an earthquake from a distance. In recent years, seismology has come into prominence in connection with the design of buildings, inasmuch as earthquake-resistant structures can be built. Again, the geophysical prospector has used methods that have been developed by seismologists to study the interior of the Earth, so that seismographic exploration by artificial explosions and the recording of their effects at a number of surrounding points, is today one of the chief means of geophysical prospecting. Seismology is closely related to Geodesy in that earthquakes frequently produce local changes in elevation and position.

Tectonophysics is that broad field of the Earth Sciences that deals with the geological structure within the Earth's crust and the causes that bring about changes in that structure both gradually and suddenly. It is closely related to structural geology, seismology and volcanology. Tectonophysics further deals with the study of the physical properties of the crustal materials of the Earth, and their behavior under intense hydrostatic pressures and high temperatures such as exist in the interior of the Earth.

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2.4. Terrestrial Magnetism deals primarily with the natural magnetic field of the Earth. Accurate magnetic maps are needed by mariners and explorers for directing their courses. Terrestrial Magnetism has of late found great importance in connection with air navigation. Inasmuch as disturbances in the magnetic field of the Earth affect telephone, telegraphic, radio and wireless telegraphic communications, the importance of Terrestrial Magnetism to communications has grown greatly in recent years. The Earth's magnetic field is very much affected by particles and wave radiations emitted from the Sun, and there is an important link between Terrestrial Magnetism and the cosmic sciences. In recent years Terrestrial Magnetism has also come to involve to a certain degree the modified magnetic fields that man is able to produce in his laboratories for special study such as atomic and nuclear physics and electronics generally. Among the many new secret devices that played an important part in the last war were the device for protecting ships against magnetic mines and the odograph or automatic map maker that was used extensively in jeeps and other vehicles of the armed services. In addition to being closely related to the mapping aspects of Geodesy and the navigational aspect of Oceanogaphy, Terrestrial Magnetism has long played an important part in civil engineering generally, and in recent years, the variation in the magnetic field due to the presence of ore-bodies of varying magnetic quality, has provided a useful method in Geophysical prospecting to determine the nature of the contents of the Earth.

The problem of natural *electric currents* in the Earth has important relationships to Terrestrial Magnetism. A magnetic storm is invariably accompanied by an increase in the earth-currents which play an important part in the disruption of communications under such conditions. The study of these currents both under normal and unusual circumstances is a work of scientific and practical importance. Electrical methods are now extensively used in Geophysical Prospecting.

2.5. *Geophysical Prospecting* relates to the study of the interior of the Earth by suitable physical methods. It thus uses the instruments of the geodesist in determining the variations in the gravitational pull of the Earth, and the seismologist's methods of studying the movements of waves through the Earth. Study of the local variations in the magnetic fields of the Earth reveals the presence of underground ore bodies. Electrical methods are used to locate non-metallic and metallic ores and water-bearing strata. In boring for oil, the discovery of the same is helped by logs of the electrical resistivity and of the porosity of the traversed strata ; and in the hands of the specially trained geologist, these logs facilitate also stratigraphical correlations. Geophysical Prospecting is usually undertaken for commercial ends, although fundamental knowledge regarding the crustal layers of the Earth also emanates from it. In general it may be said that the growth of geophysical prospecting has emphasized the importance of the various branches of the Earth sciences and their mutual interdependence.

2.6. *Meteorology* is the science of the atmosphere enveloping the earth, and as such, weather and climate form the most important parts of it. Meteorology is closely related to Hydrology which is the branch of Geophysics dealing with the waters of the Earth and to Oceanography and Atmospheric Electricity. There are certain other less obvious relationships to Seismology and Volcanology. Thunderstorms, atmospherics and the flow of electric currents in the earth's atmosphere are closely related to Meteorology. Meteorology is essential for sea and air navigation. The measurement of potential-differences within and above the earth and in clouds and of the flow of current between the earth and the atmosphere are very important in various fields of science and is of great interest to the Electrical Engineer.

2.7. *Hydrology* may be defined as a study of the waters of the land areas of the earth, their distribution and disposition, and the development of these waters for the use of man. It involves a study of the water from the time it reaches the earth as precipitation (including its intensity and distribution) until it is returned to the ocean or to the atmosphere. It is therefore closely related to Meteorology and to Oceanography. It includes not only the waters on the surface of the earth but ground-water as well. Hydrology is important in engineering, not only in connection with the proposed gigantic structures like the Damodar, the Mahanadi and the Kosi dams but also for planning extensions of wells, tanks and tube-wells. Water-supply, inland navigation, water-power, flood-control, sanitary engineering, irrigation, and drainage all involve aspects of hydrology.

Agricultural workers are interested in Hydrology because of their importance for water-supply for farms and fields. Ground-water Hydrology is sometimes accepted to be a branch of Geology although engineers interested in water-supply are equally interested.

The study of the dynamics of streams, the erosion, transportation and deposition of materials, and the study of lakes and lake-beds are also part of this broad field.

Hydrology involves snow-survey work in regions in which melting snows are an important factor in water-supply, such as in the Himalayas. This in turn is closely related to the scientific study of the physics of snow, the formation of snow-crystals, snowfall and movement, temperature-gradients in snow-banks, and the melting of snow.

Glaciology as related to living glaciers is a special branch and its study is of great interest both fundamentally and as throwing light on catastrophic floods in big rivers, as in the Indus by the burst of the Shyok Dam.

2.8. Physical Oceanography is concerned roughly with three-fourths of the surface of the earth. It deals with the tides and currents of the ocean, its shores and beds, the physical and chemical properties of the water, evaporation from its surface, and formation, movement, and dissipation of icebergs. The plant and animal life that exists in the ocean is usually considered under Marine Biology. Oceanography is likely to develop considerably because of its close relation to Meteorology, and to Hydrology and to Marine Biology. It is also closely related, in connection with the study of the ocean bed, to Tectonophysics, and may likewise involve certain aspects of Seismology and Volcanology. The charting and mapping of the ocean falls under Hydrography which may be considered to be a part of Geodesy.

III.—THE POSITION OF THE GEOPHYSICAL SCIENCES IN INDIA WITH SPECIAL REFERENCE TO THE NEEDS OF EXPLORATION GEOPHYSICS.

3.1. In India, the development of the geophysical sciences has so far been largely in the hands of Government departments. The most prominent among them have been the Survey of India, the Geological Survey of India, the India Meteorological Department and the Irrigation Departments of the Central and Provincial Governments. Work on the hydrography of the oceans round India has been mainly in the hands of the Royal Indian Marine, but officers of the Zoological Survey of India have co-operated with them in various oceanographic investigations.

The objectives of the various Government departments have been the scientific collection and consolidation of data pertaining to their various branches and the practical utilisation of them for governmental and public purposes. The economic objective has been kept in mind, but somewhat in the background.

It is generally agreed that the time has now come to emphasise the economic objective. Economic mineral deposits are usually associated with defined or definable geological structures. They often occur in pockets overlain by less useful deposits. Surface indications are not everywhere available and geophysical investigation of selected parts of India for such mineral deposits, and for buried geological structures which are likely to prove productive of economic mineral deposits, is a very important application of geophysics in India. Examination and survey of deeply buried minerals which are beyond the scope of surface geological surveys should, it is considered, be undertaken with the aid of the techniques of electric, gravimetric, magnetic and seismic explorations of the sub-surface. These methods have given good results in other countries like the U. S. A., U. K. and U. S. S. R. and it is considered possible successfully to map features down to 4,000-5,000 ft. and under favourable conditions to even 15,000 ft.

Mr. D. N. Wadia in his note on " Geophysical Surveying in India " has explained the importance and urgent need for a geophysical investigation of certain parts of India where rocks of the *Dharwar* and *Gondwana* systems as well as rocks of the

Eocene age, all of which are economically productive, lie hidden under alluvial cover along the 3,000-4,000 mile border of the Indo-Gangetic plains, or under the lavas of the Deccan. Mr. Wadia recommends that initial exploratory studies should begin at an early date for the locating of ore-deposits, coal-seams, petroleum and other minerals at *first in the alluvium area* and then in the areas of exposed rocks, *e.g.*, productive oil-fields in parts of Sind, Punjab and Assam, workable coal-deposits underlying the lava flows of the upper Mahanadi and the Godavari, the copper-bearing areas of Singhbhum and other parts of Bihar, Sikkim, Jaipur ; or the lead-zinc mines tract of Udaipur, Hazaribagh, etc.

Mr. Wadia has also listed in his note, problems of interest in the general geology and structure of India which can be tackled by geophysical methods. Two of them' are:—

(1) Proving extent, height and length of the buried ridge under the alluvium of the Punjab, detected by the gravity survey. This ridge is believed to be the cause of water-logging over large parts of irrigated Punjab ;

(2) studying the bottom profile of the Indo-Gangetic trough by seismic reflection and magnetic methods.

We shall now briefly review the work that has been done in India in the various branches of Geophysics.

3.2. Geodesy including measurements of gravity.

References.—Dr. Graaff Hunter's notes on " Gravity work in India and Burma " and on " Programme for the Frost Gravimeter ". Mr. D. N. Wadia's note on " Geophysical Surveying in India " and correspondence with Dr. Graaff Hunter.

3·2·1. The accurate survey maps of India and bordering regions on various scales which have been produced and distributed in large numbers throughout the country and which find daily use in all aspects of national life including aviation and engineering are the most important and obvious practical contributions of the Survey of India to the development of the country. The Survey of India took up gravity work as a fundamental scientific problem in geodesy with the object of determining the ellipticity of the earth along a central meridian. As it was found that the geoid differed sensibly from a spheroid, the work was extended. A general gravity survey of the whole country (India and Burma) with the aid of the pendulum was carried out between the years 1906 and 1939. 600 gravity stations were occupied, the average distance between stations being about 70 miles. This has provided a fairly complete picture of all the major regional anomalies of the gravity field. Attempts have been made to bring the results into geological relationship by Glennie. The Survey of India did not aim at intensive studies which will help commercial exploitation, but has carried out experimental observations for the location of manganese reef near Ramtek (Central Provinces) and some preliminary work in the mica belt of Bihar. A closer network of stations would be required to bring out the *local* anomalies.

On the other hand, oil companies in India have used since over 20 years in Bengal, Assam and Burma, first the torsion balance, and later on the modern gravimeters, for making detailed gravity surveys. Some work has also been done in Northwest India. The Burma Oil Company have recently published a full account of their work in Northeast India in the Quarterly Journal of the Geological Society, London.

The Punjab Irrigation Research Institute carried out a gravitational survey of the sub-alluvium of the Jhelum-Chenab-Ravi Doabs during 1927-30 by means of a torsion balance, but the survey was suspended in 1930 due to financial stringency. The work has been published as Research Publication, Vol. 6, No. 1 of the Punjab Irrigation Research Institute.

3.2.2. The Survey of India's objectives as regards gravity-work are as follows :—

India is now covered by a comprehensive network of protected ***primary bench-marks*** which area bout 50 miles apart, and ***inscribed bench-marks*** which are about 1 mile apart. The levels of these are accurately known and they are generally along roads, railways and canals.

The Survey of India proposes—

(1) First, to cover by a network of gravity stations priority areas in which the Geological Survey and the Mineral Adviser to the Govt. of India have expressed special interest. These can be used as reference stations for later detailed work ;

(2) To connect the existing pendulum stations and improve their precision ;

(3) To connect the existing levelling bench-marks of India by comparative gravity measurements ;

(4) Generally to aim at providing a ten-mile network of gravity stations all over India without relative error anywhere exceeding 1 milligal $\left(=10^{-3}\ \text{cm. sec.}^{-2}\right)$.

The Survey of India is acquiring a ***Frost Gravimeter***, a very sensitive instrument which has been used extensively in America for exploration purposes and with which gravity surveys can be made with greater speed.

It is hoped that the priority programme indicated by the Mineral Adviser and the Geological Department will be completed in about 3 years, but the time for the completion of the whole programme cannot be estimated at present and it will depend on the experience gained with work in the priority areas.

3.2.3.1. The following resolution was passed at the second meeting of the Committee :—

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"It was resolved that the Committee strongly supports the general scheme of the Survey of India to cover the whole country with gravity stations at intervals of 10 miles. It considers that it is of vital importance and highest priority that such work should be carried out in the following regions with a view to aid the development of the mineral resources contained in these areas :—

(i) the South and Southeastern margin of the Deccan traps ;

(ii) the eastern margin of the rocky terrain comprising the coal-fields of the Dharwar area in Bengal ;

(iii) the northern border of the Vindhyan plateau, especially the desert-covered Rajputana portion."

During subsequent discussions, the representatives of the Survey of India made it clear that while the Survey of India ultimately intended to cover the whole of India with a network of gravity stations at about 10 mile intervals in pursuance of normal scientific investigations forming part of their purely departmental programme, they would first tackle areas in which other departments and agencies expressed an interest, from the point of view of economic exploitation of minerals, so as to provide an accurate basis for further detailed studies of selected areas by those departments and agencies. Furthermore, since these operations would form part of the departmental programme no useful purpose would be served in providing details of personnel and costs which will be borne by the Survey of India budget. The Survey of India would expect to secure information as a result of preliminary operations with the gravimeter which, combined with indications from departments and agencies as to work of urgency, would enable them to consider plans for expansion of staff and provision of further instruments.

3·2·3·2. The following resolution was adopted at the seventh meeting of the Committee :—

"The Punjab Irrigation Department may be requested to see if it is possible for them to continue the work of gravitational survey of the sub-alluvium of the Jhelum-Chenab-Ravi Doabs which was suspended in 1930 due to financial stringency. In case the Punjab Govt. do not intend to proceed with the work the Torsion Balance which is a costly instrument may be transferred to some other Department who may be able to find use for it."

3·2·4. The following resolution regarding gravity measurements at sea was also passed in the first meeting :—

> "It was resolved that the Committee is of opinion that it is very necessary to carry out a systematic programme of gravity observations in oceans around India and for this purpose it is recommended that one or two submarines may be placed at the disposal of the Survey of India to carry out gravity observations in the seas in co-operation with the Royal Indian Navy."

3·3. Seismology and Tectono-Physics.

References—

(1) Dr. W. D. West : Presidential address on "Earthquakes in India" to the Section of Geology and Geography—Indian Science Congress (1937).

(2) Report of the Conference called by Government to formulate proposals for a proper seismological organisation in India (held on 18-1-1936 at the Geological Survey Office, Calcutta). The members of the Conference were the Surveyor General (Brig. H. J. Couchman), the Director of the Geological Survey of India (Dr. A. M. Heron) and the Director General of Observatories (Dr. C. W. B. Normand).

(3) Dr. K. R. Ramanathan : "Note on Scheme for Seismological Observatories in India."

3·3·1. The Geological Survey of India, beginning from the times of Dr. T. Oldham, has been taking a keen interest in the study of seismology in India, for nearly three quarters of a century now. In 1883, Dr. T. Oldham compiled his valuable "Catalogue of Indian Earthquakes from the earliest times to the end of A. D. 1869". Since Oldham's time, the after-effects of every major earthquake in India (and Burma) have been studied in the field by officers of the Geological Survey. Mr. R. D. Oldham's classic memoir "On the Great Assam Earthquake" of 1897 gave a great impetus to the study of seismology all over the world—in that it made clear the occurrence of three main types of earthquake waves which travel from the focus. As a result of the earthquake studies of the Geological Survey, the relationship between the geological structure of the country and the liability for occurrence of earthquakes has become well established.

3·3·2. The cognate studies of the Survey of India on gravity anomalies suggested to Brigadier Glennie the idea that areas of negative anomaly or "downwarps" in the Earth's crust are areas most liable to earthquakes. But there are important areas of negative anomaly in South India which are entirely free from earthquakes.

The correlation of these areas of negative anomaly with the geological structure is a difficult one and requires further elucidation.

3·3·3. The first seismograph in India was installed by Dr. Moos at Bombay in 1898. More instruments of the eye-reading type were later installed by the India Meteorological Department at Simla, Calcutta, Kodaikanal and Agra, and by the Survey of India at Dehra Dun. Sensitive photographic recording instruments (of the Milne-Shaw type) were installed at some of the observatories of the India Meteorological Department in 1922-25 and later at Hyderabad and Colombo. Dr. Banerji's studies of microseisms made with these instruments at Bombay have led the way in recent years to the development of a method of locating the position of storms at sea.

3·3·4. In 1938, the India Meteorological Department with the co-operation of the Survey of India, the Director of the Nizamiah Observatory and the Superintendent of the Colombo Observatory began to issue a quarterly seismological bulletin in which the analysed data of all recorded shocks were presented. For many years previously (since 1908), the India Meteorological Department had been publishing information about 'felt' shocks collected from observers of the India Meteorological Department.

3·3·5. Thus, although in a way, the Geological Survey of India, the Geodetic Survey and the India Meteorological Department were taking interest in Seismology, there was no co-ordinated sustained study of the subject. As stated by the 1936 Committee in their report " In none of the three departments, however, is the subject studied continuously : the smaller earthquake shocks receive little or no attention. There is no branch of the service nor any particular officer whose duty it is exclusively to study earthquake problems or to keep abreast with seismological research. In Japan the earthquake problem is recognised to be of vital importance because nearly the whole of the country lies within the seismic zone. There are over a hundred seismological observatories in Japan. Dr. Banerji, in his note of 1st August 1935, has pointed out that the Tokyo Imperial University has a special seismological department which maintains 25 seismological instruments of different types in continuous action in Tokyo itself. There is in Japan a large number of trained seismologists who work exclusively at seismological problems. The United States of America has over 40 seismological observatories at some of which there are scientists who devote themselves solely to seismological problems. In India, however, there are only 7 seismological observatories and no whole-time seismologists ". The Committee recommended the formation of a Seismological Branch under the administrative control of the Director General of Observatories under the technical supervision of a Committee consisting of the Director General of Observatories, the Director of the Geological Survey and the Surveyor General.

3·3·6. Towards the end of 1939, the Government after much persuasion decided to make a start, and created a post of " SpecialOfficer for Seismological Research " in Central Services Class II of the India Meteorological Department with a staff of one clerk and one peon and in January 1946, the post was changed to that of " Seismologist " in Class I.

3·3·7. The whole question was reviewed by the Geophysical Planning Committee in its first and second meetings and the following resolution was passed at its second meeting :—

> " In view of the many large schemes of construction which are now being undertaken in the earthquake zone of India and the risk of damage to them by earthquakes, the Committee strongly recommends that the seismological organisation recommended by the Seismological

Committee of 1936 should be implemented as early as possible with minor alterations. The Committee emphasised that a person of first rate ability for the post of Seismologist should be selected early, so that the organisation can proceed at a rapid rate." The objectives of the Section will, for the present, be as stated in paragraphs 4 and 5 of Dr. Ramanathan's note, *viz.* :—

(*a*) Purchase, or better, construction, and installation of instruments, to measure the accelerations, periods and amplitudes of ground movement in earthquake zones with a view to provide data for designing earthquake-resistant buildings and structures.

(*b*) Organisation of seismographic observatories to determine the distribution and frequency of earthquake shocks in the earthquake zones including study of minor shocks that precede and follow major earthquakes.

(*c*) Determination of the depths of earthquakes and of the velocities of travel of earthquake waves at different depths in different regions, and

(*d*) study of microseisms associated with disturbed weather in Indian seas.

3·3·8. Special attention should be paid to the study of earth movements at sites of big dams like the Sukkur barrage in Sind, proposed dams across the Kosi, the Sutlej, the Teesta and the Damodar rivers.

A note from the Coast and Geodetic survey, U. S. A., on planning a network of seismological stations is given in Appendix 9.

The aim should be to complete the present programme of development in *five* years from the date of sanction.

The Committee is unanimously of opinion that as recommended by the Seismological Committee of 1936, the Headquarters of the Seismological Organisation should be at Shillong. The Committee also recommends that a subsidiary station should be established at Barahakshetra in the Kosi Catchment.

Towards implementing the above resolution, the India Meteorological Department has made proposals to Government to expand its organisation for Seismology involving a capital expenditure of Rs. 2 lakhs (excluding cost of buildings) in 1947-52, and a recurring expenditure which will increase from Rs. 0·27 lakh in 1947-48 to Rs. 0·82 lakh in 1951-52. The Government of India have accepted the proposal.

3·3·9. The above programme does not take into account the development that is needed for the purposes of seismic prospecting. In these methods, explosive charges are detonated at depths of 10 to 100 ft. and more, to send impulses into the earth's crust, and these impulses (miniature earthquake waves) are picked up by very sensitive seismographs placed at different distances from the explosive charge. From measurements of the times which elapse between the shots and arrival of the impulses at the seismometers, deductions can be drawn in many instances about the form and depth of rock layers below ground. Seismic methods have been extensively used in oil exploration and for determining the depth of ice in glaciers. They will undoubtedly be of great value in determining the contours of the bedrocks under the Indo-Gangetic alluvium. The study and development of these methods should be taken up by the Geological Survey of India and the proposed Geophysical Institute. The experience and knowledge of the India Meteorological Department, it is expected, will be of great assistance in these developments.

3·4. Terrestrial Magnetism and Terrestrial Electricity.

References—

(1) Dr. Banerji's note on "Post-war plan for Geophysical Institutions"

(2) Dr. J. de Graaff Hunter's note on "Terrestrial Magnetism work in India and Burma".

(3) Dr. Ramanathan's notes on—

  (*a*) "Scheme for Magnetic, earthcurrent and cosmic-ray observatories in India."

  (*b*) "Note on Earth Currents".

  (*c*) "Brief Summary of the work done by the Carnegie Institution of Washington."

(4) Mr. B. L. Gulatee's notes on "Magnetic Programme" and "Secular Variation of magnetic declination in India".

3·4·1. A brief history of the work on Terrestrial Magnetism done by the India Meteorological Department and by the Survey of India is contained in the notes by Dr. Banerji and Dr. Graaff Hunter. At one time, there were *four* magnetic observatories in India and *one* in Burma. At present only the Magnetic Observatory of the India Meteorological Department at Alibag near Bombay remains. The importance of the continuance and the extension of systematic work on this subject will be clear if we remember the following points :—

(1) India occupies a large part of the earth's surface and the magnetism of the earth is one of its most important physical properties. In addition to a general variation of the magnetic field over the surface of the earth, it exhibits regional and local variations. Moreover, the earth's magnetic field undergoes periodic and non-periodic changes some of which are due to phenomena taking place in the upper atmosphere (ionosphere) of the earth and some to long period changes within the earth itself. The measurements made at the Indian observatories, Bombay and Trivandrum, have been responsible for a substantial addition to knowledge of the earth's magnetic field. The observatory at Bombay (now at Alibag 16 miles south of Bombay) is nearly a century old with a continuous record of observations (from 1847) and is providing valuable data for studying the secular variation of the earth's magnetic field, a phenomenon whose cause is not yet understood.

The Government of Bombay has been pressing from time to time the urgency of providing electric supply to the Alibag town and this department has been resisting the demand on the ground that it would interfere with continuity of the records of this very important observatory. But with the development of the electric grid-system in the Bombay Presidency and increasing pressure from the public, the resistance cannot be continued indefinitely and the transfer of the Alibag Observatory to a nearby site will have to be immediately taken up. Such a transfer will involve the taking of comparative observations for 2 or 3 years at the new site and at the present site at Alibag before the Alibag Observatory is closed down so that the continuty of the 100-year series of observations is not broken. The India Meteorological Department has asked the Bombay Government to suggest suitable alternative sites.

(2) In 1933, the International Union for Geodesy and Geophysics strongly recommended the re-starting of a magnetic observatory in the neighbourhood of Cape Comorin in view of its proximity to the magnetic equator. The old magnetic observatory at Trivandrum, after a very active life under Alan Broun became practically extinct by 1870. There is only one other magnetic observatory in the world near the magnetic equator—at Huancayo in Peru maintained by the Carnegie Institution of Washington. It is important that a large country like India should maintain a few well-distributed magnetic observatories, both for scientific and for immediate practical reasons.

(3) Airmen, navigators, engineers and exploration geophysicists require accurate magnetic maps. The maps now in general use were those prepared by the Survey of India from observations made on the field with portable instruments between the years 1901 and 1913 and corrected for diurnal and other variations by comparison with observations made at five fixed observatories at Bombay, Dehra Dun, Barrackpore, Kodaikanal and Toungoo (in Burma). Continuous observations with self-recording instruments at fixed observatories are necessary in order to correct the field observations for regular and irregular variations.

3·4·2. In 1914, a Committee appointed by the Government of India (consisting of Sir Gilbert Walker, F.R.S., Captain R. H. Thomas, R.C., the Surveyor General and Mr. J. de Graaff Hunter) recommended that for scientific purposes the Survey of India should maintain three observatories at Dehra Dun, Toungoo and Kodaikanal in addition to the India Meteorological Department's observatory at Bombay, but that Barrackpore could be closed. Since then, all the observatories except the one at Bombay (Alibag) have been closed down for one reason or other. The 1914 Committee also contemplated a second magnetic survey in 1935 or 1946 in order to bring the magnetic maps up-to-date. A partial survey was made in 1930 occupying stations in Northwest and Central India. In 1943, the requirements of the military showed up inaccuracies in the magnetic maps and most of the 80 repeat stations in India and Burma were re-occupied in 1943-44 with a view to revising the maps. But " the results are of lower precision than what was formerly achieved in that full correction for diurnal change and minor disturbances could not be made, lacking observatory cover ".

Dr. Graaff Hunter's remarks regarding the future of magnetic survey are reproduced below :—

" Since 1914, the balance between scientific and economic objectives has undoubtedly shifted. From a scientific point of view, it is desirable to reopen at least Dehra Dun and Kodaikanal Observatories or alternatives to them. I understand that the observatory at Kodaikanal, transferred to the Director, Solar Physics Observatory in 1916 and closed in 1923 still exists. That of Dehra Dun is no longer available and is under orders of demolition. It has been suggested that a new observatory should be constructed in Dehra Dun district outside the range of electrical developments and that with it should be associated earth current measurements. A site which I believe will serve both purposes has been provisionally selected after enquiries made as to the anticipated electrical developments in the neighbourhood. Situated some 15 miles from Dehra Dun, it is reasonably accessible, which would permit personnel employed to keep in touch with wider scientific activities at Dehra.

Kodaikanal (latitude 10°·2 N longitude 77°·5W) lies some 70 miles north of the agonic line (zero dip) which passes close to the southern tip of India. There are some advantages in using the old Observatory rather than building a new one elsewhere.

From the Survey of India point of view, and I think also for geophysical reasons, there is good reason for a regular programme of reoccupation of the Repeat Stations at intervals of five years. To my mind they give the secular changes, required particularly for keeping declination up-to-date, more practically and completely than can be derived from a limited number of observatories. The information is of increasing importance for aerial navigation. Indeed for such reasons I consider that additional Repeat Stations should be created and maintained outside the land boundaries of India in collaboration with other external agencies. A limited number of well chosen Repeat Stations will serve to keep up-to-date all land and maritime magnetic surveys."

The present position regarding magnetic "Repeat Stations" has been stated by Mr. B. L. Gulatee as follows :—

"There are 67 Repeat Stations in India, 12 Repeat Stations in Burma and 1 in the Andamans. The Indian stations have all been visited from 1943 to 1945, but owing to non-existence of observatories, the results have not been reduced with full refinements. Stations depending on Alibag and Dehra were reduced for Alibag alone and others were not reduced at all.

It is no use observing now or a year hence, because the secular variation deduced from such a short period will be burdened with considerable error. Energies must first be directed to rehabilitations of the older observatories."

* * * * * * *

"A visit to the Repeat Stations during 1943-45 revealed that the sites of some of them were becoming useless for magnetic observations, due to construction of buildings containing iron and the proximity of habitated areas. In order not to lose the continuity of our magnetic work, it was decided to select fresh suitable sites after taking simultaneous comparative observations at both the old and new ones. There were 23 such stations out of which 16 were observed last year and 7 will be observed this year. Actually, the continuity has been broken already in two respects :—

(*a*) By discontinuance of continuous magnetic observatories.

(*b*) By lack of observations at Repeat Stations in intervening years resulting in ignorance of S. V. for these years. Hence, rate of variation of S. V. cannot be determined. Nothing was done till 1931, when about half of India was done—being the portion deemed to be covered by Dehra and Colaba Observatories, the rest being deferred till Kodaikanal and Toungoo were reopened. After that, nothing till 1942-44 when we visited all Repeat Stations except Burma."

3·4·3. The Committee at its second meeting, passed the following resolution regarding magnetic observatories :-

"It was resolved to recommend to Government that the number of magnetic observatories in India and its neighbourhood should be increased to 5 as in the the past. One of these should be in South India near the magnetic equator, one at Alibag or its neighbourhood, one near Dehra Dun, one in Baluchistan and one in Burma, and earth current observations should be undertaken at the Observatory near Dehra Dun and the one in South India. The programme of work to be undertaken is given in the note prepared by Dr. Ramanathan ".

The Committee also agreed that the Alibag Observatory should be shifted to a site not likely to be invaded by electrical installations for a long time.

Regarding magnetic survey, the following resolutions were passed :—

" It was resolved that (i) the Committee is of the opinion that the Survey of India should take magnetic observations on a fundamental grid with stations at intervals of 10 miles which, apart from scientific and navigational uses, will serve as a basis for the detailed economic prospecting which would be undertaken by the Geophysical Section of the Geological Survey of India ;

(ii) the protection of magnetic repeat stations from encroachment by structures containing iron or electric power lines within a range of 100 yards is necessary, as these are destined for the determination of magnetic secular variation necessary for the maintenance of up-to-date magnetic maps (declination, inclination and horizontal force). The Committee accordingly recommends that each of the 90 repeat stations should be declared protected areas of the Survey of India. "

It was agreed that if during the course of the magnetic survey work made by the Survey of India, any anomalies were found, the information should be passed on to the Geological Survey for further detailed investigation.

(iii) Arrangements should be made to maintain continuous registrations of earth currents in *at least* two stations in India, one in South India near the magnetic equator and another in Northern India in the Indo-Gangetic alluvium of the Punjab or the United Provinces.

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3.5. Geophysical Prospecting.

References—

(1) Mr. D. N. Wadia's notes on " Geophysical Surveying in India ", and his correspondence with Dr. Graaff Hunter.

(2) Mr. Wadia's note on " Visits to geophysical stations in England ".

(3) Dr. West's note on " The Geophysical Section of the Geological Survey of India—its programme and aims ".

(4) Dr. G. Dessau's notes on " Geophysical Prospecting in India ".

(5) Dr. P. K. Ghosh's note on " Summary of the recent work on mineral springs of India by the Geological Survey of India ".

The importance of employing geophysical methods for geological prospecting work in this country has already been pointed out in the introductory remarks of Section 3.1 of this chapter.

3.5.1. In this section we shall summarise (1) what has been done in this country and (2) what is proposed to be done by the existing organisations, particularly by the Geological Survey of India, regarding the employment of geophysical methods for geological purposes.

Dr. Dessau in his note on " Geophysical Prospecting in India " has given a good summary of the work that has already been done in India. Messrs. P. Evans and W. Crompton of the Burma Oil Company have discussed in greater detail the results of the Company's gravimetric work in India and Burma in a paper "Geological factors in gravity interpretation illustrated by evidence from India and Burma" in the Quarterly Journal of the Geological Society and in a further paper on the same subject in "Science and Culture".

The most important geophysical investigations, apart from the fundamental work of the Survey of India, done so far in India are :—

(1) the use of the Eötvos torsion balance to study the slope of the hidden surface of the bed rock under alluvium in the Punjab (N. K. Bose and B. H. Wilsdon);

(2) gravity surveys in northeast India, Burma and parts of the Punjab and Sind under the auspices of the Burma Oil Company; these Surveys cover an area of about 330,000 square miles according to the figures by the Burma Oil Company, and were preceded by some torsion balance work, and accompanied and integrated by electrical resistivity, seismic refraction and seismic reflection surveys.

(3) surveys by other private oil companies in possible oil-bearing areas in Western Sind and Baluchistan;

(4) geophysical surveys by the Geological Department of the Mysore Government on sulphide ores, gold reefs, graphite deposits and determination of the depth of water table. The Mysore Geophysicist has also determined the depth of bed-rock along the site of the proposed dam across the Godavari;

(5) application of electrical, magnetic and gravimetric methods by the Geological Survey and the Survey of India for (*a*) prospecting for mica pegmatites (electrical methods), (*b*) prospecting for manganese ores (gravimetric and magnetic methods), and (*c*) for dam foundations, river sand supplies, water resources, etc. (mainly electrical methods), (*d*) prospecting for iron ores (magnetic methods), (*e*) delimiting geological boundaries and potentially coal-bearing areas in coalfields (electrical methods).

3.5.2. The Geological Survey's programme. The Geological Survey have recently started a Geophysical Section under the charge of Dr. G. Dessau, an experienced Geophysicist. The Section is now concentrating attention on recruitment and training of young geologists and geophysicists for geophysical work, organisation of a laboratory and workshop for building and testing instruments for field work, and organisation of field work for solving specific problems. Already now, less than two years after the starting of the Geophysical Section, the number of officers engaged on geophysical work is about eighteen, together with a similar number of surveyors and specialised workmen; but further increases of the staff will soon follow.

(1) The Geophysical Section will for the moment concentrate on numerous immediate problems connected with dam foundations, river sand supplies, metalliferous and coal deposits, etc., using mainly electrical and magnetic methods, shallow-depth seismics and the so called other "minor methods".

(2) As a long-range scheme they will keep in their programme the study of the bottom of the Indo-Gangetic trough. This problem will, it is expected, keep at work officers and equipment temporarily freed from other immediate commitments.

(3) The Section will build up a laboratory and research organisation at Headquarters to deal with the determination of the geophysical properties of rocks, with development and testing of equipment, with model experiments and with interpretation of results.

What the India Meteorological Department and the Survey of India propose to do by way of establishing observatories and carrying out systematic survey-work has already been indicated.

3.5.3. The note by Dr. P. K. Ghosh mentioned at the beginning of this section gives an idea of the work which has been done by the Geological Survey on mineral springs in India, their rates of flow, temperatures, radio activity, chemical contents, etc. It is possible that some of them will be suitable for commercial exploitation. The Geological Survey hopes to bring out a monograph on this before long.

3.5.4. Dr. M. S. Krishnan, Superintending Geologist of the Geological Survey of India, has recently been sent to the United Kingdom to study the work that is being done there on uranium and other radio active minerals. This subject is, however, being handled in detail by the Atomic Research Committee.

3.5.5. The recommendations of the Committee for co-ordinating the existing resources and developing them are given in the form of a resolution passed at its fourth meeting :

> " As an interim measure, the Committee was of opinion that a Standing Committee consisting of the following should be formed with the object of :—
>
> (i) co-ordinating the existing resources of the scientific departments and universities in Geophysics for research, field work and training of personnel,
>
> (ii) developing these resources, and
>
> (iii) implementing the recommendations of the Committee for a Central Geophysical Institute."

The suggested composition of the Committee is as follows :—

Representatives of—

(1) The Survey of India.

(2) The Geological Survey of India.

(3) The India Meteorological Department.

(4) The Central Waterways, Irrigation and Navigation Commission, and

(5) Two representatives of the National Institute of Sciences of India.

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3.6. Meteorology and Atmospheric Electricity.

References.—Dr. Banerji's note on " Atmospheric Electricity " and Dr. Ramanathan's note on " Scheme for magnetic, earth current, and cosmic-ray observatories in India ".

By reason of India's extensive coastline, the size of the country, and its position on international air-routes, and the value of sea borne traffic for her economy, the importance of an efficient meteorological service is obvious and needs no special emphasis. Well-organised meteorological observations are also required for other national purposes such as agriculture, irrigation, and public health. Meteorology proper was not discussed by the Committee because the subject was already receiving full attention from the India Meteorological Department and there were in existence an Atmospheric Research Committee and a Services Committee dealing with it. However, Meteorology in its relation to Hydrology was discussed and the conclusions are set out in a later section under Hydrology.

The work so far done in India on atmospheric electricity has been mainly by the India Meteorological Department at its Observatories at Simla, Bombay and Poona, although some work has also been done by individual workers in universities. The Indian work has made substantial advances in our knowledge of the elctricity of thunderstorms and of rain and snow. The Department has recently started work on the timing and location of atmospherics or electrical disturbances due to thunderstorms. The recording of potential gradient is being done at Colaba and Poona, but active work on the subject of atmospheric electricity is somewhat in abeyance owing to lack of staff and organisation. The Committee recommended (1) that work on atmospheric electricity should be systematically pursued at Bombay, at a northern Indian station like Delhi or Dehra Dun, at Calcutta and at a South Indian station near the magnetic equator ; and (2) it would be advantageous to associate the earth current and atmospheric observatories with the magnetic observatories wherever possible.

3.7. Hydrology.

Reference.—Note dated 30th August 1946 by Mr. N. D. Gulhati. Secretary, Central Board of Irrigation, on the "Present position and proposals for the collection of basic hydrologic data in India".

3.7.1. The Central Board of Irrigation, the Agriculture, Irrigation and Forest Departments of different Provinces and States, the India Meteorological Department, the Geological Survey of India and the Central Waterways. Irrigation and Navigation Commission are all interested in the study of this subject. The growth of large-scale undertakings necessarily involves as precise a knowledge as possible of the water-income from rain and snow, loss of water by evaporation and other ways, overground storage as snow or as water, underground storage, flow of water in rivers and the quality of their waters. Considering the size of the country and the variability of the factors involved, the amount of data to be collected is very large.

3.7.2. There are about 3,000 raingauges over the country maintained under various Provincial, State and local administrations. The India Meteorological Department has been the main agency for standardising and collecting rainfall and snowfall, temperature, humidity, wind and evaporation data. The Central Board of Irrigation has, during the last few years, taken much interest in collecting various kinds of hydrologic data and their publication. It is understood that there are other raingauge stations maintained by various provincial and State departments, the data from which are not included in the published Annual Rainfall Data. As regards run-off of rivers we have some information collected in the Punjab, Sind and Madras. There is also some system of observing water levels in wells in the Punjab, Sind, the United Provinces and Bombay. More work is required to standdardise the methods and publish the results in a systematic manner.

3·7·3. At a meeting held on the 10th August 1916 between representatives of the Central Waterways, Irrigation and Navigation Commission and the India Meteorological Department, an Officer of the Punjab Irrigation Department and the Secretary, Central Board of Irrigation, the general policy for the collection of some of the basic hydrologic data in this country and also the special requirements of the Kosi, Damodar, Mahanadi, Sone, Chambal, etc., catchments were discussed. A copy of the proceedings of this meeting is given in Appendix 21. Recommendations relate to the following topics :—

(1) Precipitation (both rainfall and snowfall) ; study of amounts and frequencies of intensities.

(2) Snow surveying (above snow-line).

(3) Related meteorological data such as temperature, humidity, wind, evaporation, etc.

3.7.4. The Central Waterways, Irrigation and Navigation Commission has under consideration a plan of river-gauging and discharge observations on all the important rivers of the country.

3.7.5. The Central Board of Irrigation, at its annual meeting held in November 1946, passed resolutions recommending the collection of various hydrologic data. A copy of the resolutions is given in Appendix 22.

The main points about the recommendations are :—

(1) *Precipitation.*—(*a*) The total number of raingauge stations should be increased so that the amount of water falling as precipitation can be estimated correct to within 10 per cent. over each important catchment in the country. Snowgauges should be installed at a sufficient number of high level stations in the Himalayas.

(*b*) Self-recording raingauges should be installed at 10 per cent. of the India Meteorological Department observatories and of new stations to be set up in catchment areas in connection with projects.

(*c*) All rainfall observatories in India should come under the standardising and inspecting influence of the India Meteorological Department. They should continue to compile and publish all precipitation data. Unpublished data should be scrutinised and published.

(*d*) Detailed studies of frequencies of rainfall intensities, trends, etc., should be made for each individual catchment.

(2) *Snow-Surveying.*—Dr. J. E. Church* of the Agricultural Experimental Station, Nevada and the President of the International Commission on Snow should be invited to come out to India in the spring of 1947 to advise on snow-surveying in the river catchments of the Himalayas.

(3) *Related meteorological data.*—The number of stations recording related meteorological data should be increased considerably. In hilly areas, there should be at least one temperature and wind recording station at every 2,000 ft. interval of height.

(4) *River flow and discharge.*—Along every important river in the country, gauge and discharge sites should be established at a number of points along its length and regular observations maintained for a period of at least 20 to 30 years. The collected data should be published in a standardised manner.

(5) *Ground water supplies.*—An inventory should be made of the work already done and being done in the country. The actual investigations regarding underground water-supplies should be mainly the responsibility of local administrations, but the Central Waterways, Irrigation and Navigation Commission's organisation should assist in standardising and co-ordinating the work. Studies on infiltration and subsoil flow should be undertaken at Irrigation Research Institutes.

(6) *Quality of natural waters.*—The chemical contents of subsoil waters have to be investigated and tracts in which irrigation by subsoil water causes deterioration of land demarcated. Silt contents of rivers and their variations should be studied.

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*Dr. Church has since visited India and led a survey party to the Teesta and Kosi basins (*vide* 3·7·6 below). He and members of the party are now preparing full reports which, when received, should be considered by the Standing Committee for Geophysics after which suitable recommendations should be made to the Government.

(7) The research and inspecting organisation of the India Meteorological Department should be expanded so that they can improve and expand the hydrometeorological organisation in this country.

(8) The work of the hydraulic research laboratories in India (and Ceylon) should be expanded so that they become first class research stations.

(9) The Central Waterways, Irrigation and Navigation Commission and the Central Board of Irrigation should recommend standard apparatus and methods for making river discharge measurements and collection and publication of river discharge data ; and

(10) A study should be carried out of the water balance of a defined catchment taking into account as scientifically as possible all the factors which enter in the water economy of the catchment. For this purpose, it has been proposed that the Damodar Catchment should be chosen for investigation.

3.7.6. These recommendations were generally approved by the Geophysical Planning Committee at its Bombay meeting on 2nd September and at the Delhi meeting on the 25th November 1946.

Dr. Church came out to India in March 1947 and snow-survey parties visited snowfields in the Teesta and Kosi Catchments in April and May 1947. The Central Waterways, Irrigation and Navigation Commission and the India Meteorological Department are taking all necessary action for implementing as many of the above recommendations as possible.

The committee notes that the number of discharge gauges is very inadequate and urgent steps should be taken to provide an adequate number of discharge gauges. The United States of America has about 10,000 (ten thousand) stream gauge stations, while in India we have hardly 200.

3.8. **Oceanography.**

Reference.—Dr. Ramanathan's note on " Physical Oceanography ".

The note prepared by Dr. Ramanathan on Oceanography was considered. Systematic collection of information about air and sea temperatures, salinity, tides, ocean currents, etc., at different depths in Indian waters is of great interest to meteorologists and marine biologists. The study of marine sediments and their past and present environments is developing into a new branch of science of great importance for our understanding of the history of the earth and of the origin of petroleum.

The Committee recommends that a plan for the development of oceanography should be worked out by another Committee consisting of :—

(1) Members of the present Planning Committee for Geophysics, and

(2) Representatives of :—

(*a*) the Royal Indian Navy,

(*b*) the Zoological Survey of India,

(*c*) Provincial Governments which maintain Departments of Fisheries.

IV.—CENTRAL GEOPHYSICAL INSTITUTE.

Reference.—Professor Saha and Mr. Sen's Scheme for a Central Geophysical Institute for India.

In his proposal to Government for the constitution of the Planning Committee for Geophysics, the Director General of Observatories suggested that the Committee should consider the question of setting up a Central Geophysical Institute which would keep itself up-to-date in all the latest developments regarding geophysical research and geophysical prospecting and would itself undertake research on such developments, be able to give advice on questions of prospecting by physical methods and undertake such prospecting.

The question was discussed in a general way at the first meeting of the Committee held at Calcutta in February, 1946. The importance of developing an organisation for training specialists who will be able to undertake geophysical exploration and interpret the results, was emphasised and the following tentative conclusion was recorded :—

> "The Committee is of opinion that India should have a Central Geophysical Institute which should work in close collaboration with the Survey of India, Geological Survey of India and the Meteorological Department and should have a constitution similar to those of the National Physical and Chemical Laboratories. Its location requires more consideration. It should undertake fundamental work in : (*a*) the measurement of gravity, (*b*) seismic methods of prospecting, and (*c*) magnetic and electrical surveys. It should have an annual programme of field work which should be planned in consultation with the above departments. It should also encourage teachers of Physics and students from different universities to come to it and undertake research work in different branches of Geophysics."

Professor Saha was asked to prepare a plan for the proposed Institute.

In the third meeting (Bombay, September 1946) various members expressed the view that the provision of courses and facilities for research work in Geophysics should be the function of the universities ; that the Survey of India and the Geological Survey of India were providing facilities for advanced studies and research in the branches of Geophysics in which they are concerned ; therefore, it would be unnecessary duplication if the proposed Institute was to do the same or similar work. The conclusion of this meeting, as summarised by the Chairman, Mr. Wadia, in winding up the debate, was as follows :—

> "That while the meeting reiterated the aims and objects of a Central Institute for Geophysics as defined in the proceedings of the first meeting of the Committee at Calcutta, the establishment of a full-fledged Institute with its own laboratory and workshop, library and professorial establishment in all the different branches of geophysics would involve a heavy outlay and also a certain amount of duplication of work already being done or proposed to be done by the different departments. Therefore, for the present the proposed Institute should function through the specialised branches of the existing scientific departments—the Meteorological Department, the Geological Survey of India, the Survey of India, the Central Board of Irrigation and the University Post-Graduate Research Institutions. Co-ordination of policy and programme should be ensured by the creation of a Board of Direction invested with proper authorities from the Central Government. The Board should consist of the heads of the departments mentioned and should include two representatives of the National Institute of Sciences of India. The Board should maintain contact with the different universities and arrange to provide facilities for advanced studies and research in particular branches of geophysics to such post-graduate students as may desire to take up such courses."

Prof. Saha, who had not been able to attend the Bombay meeting, and had made considerable progress in drafting the plan which he had been asked to prepare at the first (Calcutta) meeting, did not agree that the subject had been considered in all its bearings at the Bombay meeting, and suggested that the conclusion of the Bombay meeting should not prejudice the consideration by the Committee of the plan prepared by him.

The aims of the Institute, as proposed in Prof. Saha's plan, are (*a*) the training of Applied Geophysicists, capable of exploring the oil and mineral resources of India, and (*b*) Geophysical research.

The plan assumes that students seeking admission to the Institute have graduated at a University in at least two of the three subjects: Mathematics, Physics and Geology. The Institute will offer a three years' "graduate" course, the curricula of which will cover Mathematics, Physics, Geology and Geophysics; students will have the option of specialising either as (*a*) Petroleum Geophysicists or (*b*) Mining and Engineering Geophysicists. The Institute will also provide a "post-graduate" course of one year's duration, comprising the study of advanced methods of prospecting (radio-active, geothermal, electrical and gravitational). This will qualify the graduates as "Geophysical Technologists".

The Institute will maintain a programme of research and field investigations. The organisation of field parties will be done in collaboration with the Survey of India, the Geological Survey of India and other interested Government organisations. The Institute will co-operate with petroleum, mining and engineering industries and make available such expert advice as they may need in matters of geophysical exploration.

They will require a Physical Laboratory, a Geological Laboratory and a well-equipped Geophysical Laboratory with various divisions—Magnetic, Gravitational, Seismic, Geothermal and for Radio-activity. The staff will include a Director (who will be an eminent Geophysicist), one Professor each in the divisions of Physics and Mathematics and two Professors each in the divisions of Geology and Geophysics; 12 Lecturers; 4 Senior Scientific Officers; 6 Junior Scientific Officers; 17 Scientific Assistants; also laboratory and workshop and clerical staff.

The costs involved, on a rough calculation, are as follows :—

	Rs.
Non-recurring—	
Buildings (including furniture)	10 lakhs.
Laboratory equipment	5 ,,
	15 ,,
Recurring—	
Salaries of staff and stipends to research scholars	3·7 lakhs.
Travelling allowances	0·1 ,,
Maintenance of laboratories	0·4 ,,
Contingencies	0·1 ,,
	4·3 ,,

Prof. Saha's plan was placed before the fourth meeting of the Committee (Delhi, November 1946). After discussion, the Committee was of opinion that the scheme was acceptable in principle as a long-term plan, and attempts should be made to bring the Institution into existence within a reasonable period of time. The scheme should be circulated amongst different Universities and Research Institutions of India to elucidate their opinion as to whether any of them was willing to undertake the scheme in whole or in part and if so, what assistance they would require towards that objective.

A letter was addressed to the Universities and Scientific Research Institutions, enclosing a copy of the plan for the Central Geophysical Institute, and these bodies generally welcomed the formation of a Central Geophysical Institute.

Views received from various Universities and scientific institutions and those expressed by the members of the Committee were discussed at the 6th meeting of the Committee and the following resolutions were passed :—

"(i) The Committee is of opinion that in order to expedite the development of Geophysics in this country, Indian Universities teaching M.Sc. course in Geology, Physics and Mathematics should institute a course in Geophysics for the M.Sc. degree. Only B.Sc. students taking combinations of at least two of these three subjects should be allowed to take the course. There ought to be a separate Department of Geophysics, with proper geophysical staff.

(ii) The Committee recommends that the Government of India should give adequate financial aid to such Universities as satisfy conditions in para. (*i*) above for starting geophysical courses in the M.Sc. stage.

(iii) The Committee further recommends that in order to give effect to these ideas, the Government should appoint an officer who should get into contact with universities and other institutes of university rank. The officer selected for the purpose should be a technical man having a sound knowledge of Geophysics or Physics or Geology.

(iv) If for any reason the Central Government is unable to assist the Universities, the Central Geophysical Institute should be started immediately and should deal both with post-graduate teaching as well as post-M.Sc. teaching and research as contemplated in the report on the Central Geophysical Institute. Any duplication between the universities and the Central Geophysical Institute should be avoided ".

V. NEED FOR FORMING AN INDIAN NATIONAL COMMITTEE FOR GEODESY AND GEOPHYSICS, REPRESENTATIVE OF ALL BRANCHES, AND AFFILIATING IT TO THE INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS.

As Geophysics embraces many fields of knowledge and has for its scope the earth as a whole, it is a science in which world-wide co-operation is of special importance. With a view to secure such international co-operation, the International Union of Geodesy and Geophysics was formed many years ago in 1919. India was a member of this Union from 1930 to 1933, but for financial reasons, dropped out from the Union in 1933. It has now again become a member in 1947.

The objects, composition and membership of the International Union, as extracted from the Preliminary Draft Convention and bye-laws placed before the meeting of the Executive Committee of the Union held at Oxford on December 10-14, 1945, are given below :—

"*Objects, Composition and Membership of the Union.*—(1) The objects of the Union are :—

(*a*) To promote the study of problems relating to the figure and physics of the Earth.

(*b*) To initiate and coordinate research which depends on international co-operation, and to provide for comparison, discussion and publication.

(2) The Union is composed of a number of Associations, each of which is responsible for a separate branch of Geodesy and Geophysics.

(3) The Union adheres to the International Council of Scientific Unions, and supplies two members to its Executive Committee.

(4) Any country, or any territory in which independent scientific activity has been developed, may adhere to the Union providing that it takes an adequate share in its upkeep. The adhering body may be the Government or the Academy of Science, or any other body or department of scientific and representative character. In every case correspondence on all matters other than the Convention shall be conducted between the Union and an authorised scientific body."

"*Bye-laws regarding objects, composition and membership of the Union.*—(1) The following are the constituent Associations of the Union :—

(*a*) The International Association of Geodesy,

(*b*) The International Association of Seismology,

(*c*) The International Association of Meteorology,

(*d*) The International Association of Terrestrial Magnetism and Electricity,

(*e*) The International Association of Physical Oceanography,

(*f*) The International Association of Volcanology,

(*g*) The International Association of Scientific Hydrology,

(2) New branches, requiring independent incomes, start as Committees under the Union, attaining separate status as, and when, necessary.

(3) The President and General Secretary of the Union shall serve on the Executive Committee of the International Council of Scientific Unions.

(4) International cooperation requires close and personal touch between the officers of the Union and the scientists representative of each branch, or Association, in the adhering countries. Adhering countries are asked to form National Committees, representative of all branches, and to encourage direct touch between them and the Union".

In India, geophysical work in its various branches comes under the jurisdiction of a considerable number of Government departments and institutions. It is therefore particularly necessary for India to organise a National Committee for Geodesy and Geophysics composed of representatives of different Government Departments working in the various branches of the subject and of a few selected non-official scientists who are keenly interested in the subject. This National Committee can then get into touch with the International Union.

(1) *National Committee of Geodesy and Geophysics.*—The Committee considers that the time has now come for the formation of a National Union of Geodesy and Geophysics, and that the National Institute of Sciences of India be requested to form this organisation and to take steps for its affiliation with the International Union of Geodesy and Geophysics.

Note.—The National Institute of Sciences has already proceeded to form such a Committee.

(2) *Standing Committee for co-ordination.*—The Committee was of opinion that a Standing Committee consisting of the following should be formed with the objects of :—

(i) co-ordinating the existing resources of the Scientific Departments and Universities in Geophysics for research, field work and training of personnel ;

(ii) developing the resources, and

(*iii*) implementing the recommendations of the Committee for a Central Geophysical Institute.

The suggested composition of the Committee is as follows :—

Representatives of—

(1) The Survey of India,

(2) The Geological Survey of India,

(3) The India Meteorological Department,

(4) The Central Waterways, Irrigation and Navigation Commission,

(5) The Central Board of Irrigation,

(6) Three scientists to be nominated by the National Institute of Sciences of India.

VI. SUMMARY OF RECOMMENDATIONS.

In this chapter, the main recommendations of the Geophysical Planning Committee are summarised.

6·01 Province of Geophysics.

It was agreed that the province of geophysics for the purposes of the Committee should be taken to consist of—

(1) Geodesy, including measurements of gravity,

(2) Seismology,

(3) Terrestrial Magnetism and Earth Currents.

(4) Geophysical Prospecting,

(5) Meteorology, including Atmospheric Electricity,

(6) Hydrology,

(7) Oceanography.

Meteorology was, however, excluded from any detailed consideration except in its relation to hydrology, because it was receiving full attention from the India Meteorological Department and there were two other Government Committees, the Atmospheric Research Committee and the Joint Meteorological Committee dealing with it.

6·02 Scope of the work to be done by the Committee.

It was agreed that the Committee should—

(1) prepare a plan for geophysical work in India making use of the existing organisations and expanding them where necessary.

(2) define the fields of responsibility of different departments and institutions and suggest methods of co-ordinating the work as a whole ;

(3) prepare plans for a Central Geophysical Institute ;

(4) work out requirements as regards finance and personnel, wherever necessary.

6·03 Geodesy, including measurements of gravity.

It was resolved that the Committee strongly supports the general scheme of the Survey of India to cover the whole country with gravity stations at intervals of ten miles. It considers that it is of considerable importance and high priority that such work should be carried out in the following regions with a view to aid the development of the mineral resources contained in these areas :—

(i) the south and southeastern margin of the Deccan traps,

(ii) the eastern margin of the rocky terrain comprising the coal-fields of the Dharwar area in Bengal ; and later,

(iii) the northern border of the Vindhyan plateau and southeastern Rajputana.

The representatives of the Survey of India stated that after making preliminary experiments with the Frost Gravimeter they would undertake the work outlined above in pursuance of their departmental programme and work out plans for the necessary expansion of staff and provision of instruments. They will first tackle areas in which the Adviser on Mineral Development and the Geological Survey have expressed interest from the point of view of economic exploitation of minerals.

6·04 Seismology.

It was resolved that in view of the very large schemes of construction which are now being undertaken in the earthquake zones of India and the risk of damage from earthquakes, the Committee strongly recommends that the seismological organisation recommended by the Seismological Committee of 1936 should be implemented as early as possible with the alterations suggested by Dr. Ramanathan. The Committee has emphasised that a person of first rate ability for the post of seismologist should be selected early so that the work can proceed at a rapid rate.

The Committee has noted that the Director General of Observatories has, in his 1947-48 budget, obtained the sanction of the Government of India for the purchase of instruments and the establishment of an expanded headquarters office for Seismology. The Seismological Scheme will involve a non-recurring expenditure of Rs. 2 lakhs in addition to buildings in the five years 1947-51 and an average annual expenditure of Rs. 80,000.

6·05 Terrestrial Magnetism and Earth Currents.

(*a*) The Committee agreed to the following recommendations of Dr. Banerji and Dr. Graaff Hunter regarding magnetic observatories and maintenance of magnetic repeat stations :—

(1) Shift of Alibag Observatory to another location not likely to be affected by electrical installations for a long time.

(2) Re-establishment of magnetic observatories at or near Dehra Dun and in a suitable locality near the magnatic equator.

(3) Quinquennial occupation of existing repeat stations of the Magnetic Survey of India, 1901-1914 ;

(4) Quinquennial occupation of additional repeat stations outside the boundary of India to be created and maintained in collaboration with external agencies.

In pursuance of the above, *it was resolved* to recommend to Government that the number of magnetic observatories in India and its neighbourhood should be increased to 5 as in the past. One of these should be in South India near the magnetic equator, one at Alibag or near its neighbourhood, one near Dehra Dun, one in Baluchistan and one in Burma ; earth current observations should be undertaken at the Observatory near Dehra Dun and the Observatory in South India. The programme of work to be undertaken is given in the note prepared by Dr. Ramanathan.

(*b*) Further, it was resolved that the Committee was of the opinion that :—

(i) the Survey of India should take magnetic observations on a fundamental grid with stations at intervals of ten miles which, apart from scientific and navigational uses, will serve as a basis for the detailed economic prospecting which would be under taken by the Geophysical Section of the Geological Survey of India ;

(ii) the protection of magnetic repeat stations from encroachment by structures containing iron or electrical power lines within a range of 100 yards is necessary as these are destined for the determination of magnetic secular variation necessary for the maintenance of up-to-date magnetic maps (declination, inclination or horizontal force). The Committee accordingly recommends that each of the repeat stations should be declared " protected areas " of the Survey of India.

(*c*) It was further agreed that if during the course of the magnetic survey made by the Survey of India any anomaly is found, the information would be passed on to the Geological Survey for further detailed investigation.

Regarding magnetic observatories and magnetic survey, action should be taken by the India Meteorological Department and the Survey of India respectively as part of their departmental programme.

6·06 Geophysical Prospecting.

The Committee welcomes the formation of the Geophysical Section of the Geological Survey of India and recommends that all possible assistance should be given to the Geological Survey by the Government and by other scientific departments for extending their geophysical activities.

6·07 Atmospheric Electricity.

The Committee recommended :—

(1) that work on atmospheric electricity should be systematically pursued at Bombay, at a northern Indian station like Delhi or Dehra Dun, at Calcutta and at a South Indian station near the magnetic equator, and

(2) it would be advantageous to associate the earth current and atmospheric electricity observatories with the magnetic observatories wherever possible.

6·08 Hydrology.

The Committee approved the programme of development of Hydrology agreed to between the Central Waterways, Irrigation and Navigation Commission, the Central Board of Irrigation and the India Meteorological Departmnt (*vide* Appendices 21 and 22). The aims of the development are the collection of all relevant hydrological data of river catchments in the country, with high priority to catchments in which projects are planned, with a view to enable calculations of run-off and predictions of individual floods within defined limits of error. The main features of the programme are :—

(1) the improvement of the rainfall organisation involving an increase in the number of rainfall recording stations, especially stations equipped with self-recording instruments ;

(2) an increase in the number of stations recording temperature, wind and evaporation ;

(3) establishment of stations for observations of snowfall at high levels and of snow-surveys in the Himalayan catchments ;

(4) systematic measurement of river supplies and the publication of the collected data in a standardised manner ;

(5) collection of information about under ground water supplies ;

(6) the determination of water-balance in selected catchment areas.

The Central Waterways, Irrigation and Navigation Commission and the India Meteorological Department are taking necessary action for implementing the recommendations. The scheme is estimated to cost about Rs. 9 lakhs in the next three years.

6·09 Oceanography.

The Committee recommends that a plan for the development of Oceanography should be worked out by another Committee consisting of :—

(1) members of the present Planning Committee for Geophysics,

(2) Representatives of :—

(*a*) the Royal Indian Navy,

(*b*) the Zoological Survey of India,

(*c*) Provincial Governments which maintain Departments of Fisheries.

6·10 Central Geophysical Institute.

Prof. Saha has prepared a plan for a Central Geophysical Institute in India and various Universities and Scientific Institutions have expressed their views on it. The proposed Institute involves on a tentative estimate a non-recurring expenditure of about 15 lakhs and a recurring expenditure of about 4·3 lakhs per annum :—

(i) The Committee is of opinion that in order to expedite the development of Geophysics in this country, Indian Universities teaching M.Sc. courses in Geology, Physics and Mathematics should institute a course in Geophysics for the M.Sc. degree. Only B.Sc. students taking combinations of at least two of these three subjects should be allowed to take the course. There ought to be a separate Department of Geophysics, with proper geophysical staff.

(ii) The Committee recommends that the Government of India should give adequate financial aid to such universities as satisfy conditions in para. (*i*) and are considered suitable for such purpose by the Standing Committee for Geophysics.

(iii) The Committee further recommends that in order to give effect to these ideas, the Government should appoint an officer who should get into contact with universities and other institutes of university rank. The officer selected for the purpose should be a technical man having a sound knowledge of Geophysics, or Physics or Geology. The officer should report to the Standing Committee which would advise the Government on the matter.

(iv) If for any reason the Central Government is unable to assist the universities, the Central Geophysical Institute should be started immediately and should deal both with post-graduate teaching as well as post-M.Sc. teaching and research as contemplated in the report on the Central Geophysical Institute. Any duplication between the universities and the Central Geophysical Institute should be avoided.

6·11 Need for formation of a National Committee of Geodesy and Geophysics, and a Standing Committee for co-ordination.

(1) *National Committee of Geodesy and Geophysics.*—The Committee considers that the time has now come for the formation of a National Union of Geodesy and Geophysics, and that the National Institute of Sciences of India be requested to form this organisation and to take steps for its affiliation with the International Union of Geodesy and Geophysics.

(2) *Standing Committee for co-ordination.*—The Committee was of opinion that a Standing Committee to be called the Central Board of Geophysics consisting of the following should be formed with the objects of :—

(i) co-ordinating the existing resources of the Scientific Departments and Universities in Geophysics for research, field work and training of personnel,
(ii) developing these resources, and
(iii) implementing the recommendations of the Committee for a Central Geophysical Institute.

The suggested composition of the Board is as follows :—

Representatives of—

(1) The Survey of India,
(2) The Geological Survey of India,
(3) The India Meteorological Department,
(4) The Central Waterways, Irrigation and Navigation Commission,
(5) The Central Board of Irrigation,
(6) Three scientists to be nominated by the National Institute of Sciences of India.

The Board will elect its own Chairman who will hold office for two years. He should be assisted by a permanent secretary, who should be an experienced Class I Officer obtained from one of the Departments on a tenure basis, and a small office.

G. Dessau
D. N. Wadia
M. N. Saha
A. N. Khosla
N. D. Gulhati
W. D. West
S. K. Banerji

Simla, 12th June 1947.

C. A. K. Wilson
29th August 1947.

B. L. Gulatee
28th October 1947.

I agree, subject to one reservation, namely, that in my view, the three additional scientists to be included in the proposed Standing Committee for co-ordination (Section V) should be nominated, *not* by the National Institute of Sciences, but by the Government of India. My reason for this view is that there is a strong body of scientists in India who do not agree that the National Institute of Sciences, as it is at present, is the sole representative scientific body in India.

K. R. Ramanathan
7th August 1947.

APPENDIX 1.

INDIA METEOROLOGICAL DEPARTMENT.

Subject.—POST-WAR PLAN FOR GEOPHYSICAL INSTITUTIONS.

Government were informed that the post-war plan for geophysical institutions is under consideration of this Department and that the matter will require discussion with the officers of the Survey of India and of the Geological Department. This is necessary as all the three departments, namely, the India Meteorological Department, the Survey of India and the Geological Department have contributed to and also collaborated with each other in the past in geophysical work in India. The geophysical programme consists of :—

(a) *Magnetic observations.*—The main magnetic observatory in India, namely the one at Colaba, Bombay, transferred to Alibag in 1904 in consequence of the electrification of the town of Bombay, originally started work in 1820 and was later organised to take a full and satisfactory series of observations in 1847. For a time, the observatory was under the provincial Government and later came under the Government of India (Meteorological Department). More than a century's work has been done at the station and the record constitutes a very valuable series for the study of day to day magnetic variations, the variations according to solar cycles and secular variations. It is one of the oldest magnetic observatories in the world and is next to Greenwich. In addition to this observatory at Colaba, the Survey of India organised magnetic observatories at Dehra Dun, Barrackpore, Toungoo and Kodaikanal and for a period, a magnetic observatory was set up near Trivandrum by the Government of Travancore. The Survey of India also arranged to take short-period magnetic observations at a close network of stations and also at a number of " repeat stations " for the preparation of magnetic maps for the country as a whole. As a result of the retrenchment campaign in 1932, the Survey of India closed down the magnetic observatories at Toungoo, Barrackpore and Kodaikanal, even though the Committee appointed by the Government of India (with Sir Gilbert Walker as Chairman, the Surveyor General of India and Dr. Graaff Hunter as members) in about 1920 recommended the continuance of these observatories except Barrackpore. The Dehra Dun observatory was maintained until 1941, when a severe flooding of the underground magnetograph building led to a cessation of further observations. It is understood that during the war the Survey of India found it necessary to arrange to take magnetic observations at a very large number of stations to bring magnetic maps (maps of magnetic declinations, etc.) to date and much deplored the break in the magnetic observations which resulted from the retrenchment campaign, because it was found very difficult to link up the long break.

(b) *Seismological observations.*—The question of seismological observations was reviewed in 1936 by a Seismological Committee formed of the Director General of Observatories, the Director, Geological Survey and a representative of the Survey of India. This Committee reported to Government certain developments in the seismological observations. The report was accepted by Government, but sanction to the scheme was postponed on account of the war.

The Geological Department have published a large number of monographs giving detailed study and survey of earthquakes in the Indian and neighbouring areas. Indeed, that Department can be proud of its very valuable contributions made to earthquake studies. Dr. Oldham's monograph on the great Assam earthquake of 1897 gave for the first time classification of the principal earthquake phases and he is rightly regarded as one of the pioneers of seismological science. The contributions of Dr. Middlemens in connection with the earthquake studies are also very valuable. Field studies of earthquake effects must remain the work of the Geological Department.

(c) *Earth currents.*—These are the currents which seriously affect telegraphic lines during magnetic storms. Very little systematic observations of earth current have been taken in India. The earth currents constitute the electric counterpart of the magnetic variations. A few sporadic observations taken with telegraph lines are available. Some observations were taken by Dr. S. K. Banerji and were published in the Memoirs of the India Meteorological Department, Vol. 26. The observations of earth currents have been started in other parts of the globe ; these are being recorded in a very systematic way at Watheroo in Australia. It is most desirable, that in India there should be at least one station taking continuous records of earth currents and studying them in relation to magnetic variations.

(*d*) *Atmospheric electricity.*—This involves observations of the fine weather electricity in the atmosphere as well as electricity of thunderstorms. These have been studied at this department's observatories in Bombay and Poona.

(*e*) *Observations relating to Ionosphere.*—The variations of the electrical conditions in the ionosphere have a close relationship with the magnetic variations. None of the three Departments has any arrangements for taking ionosphere observations. The All-India Radio is taking some systematic observations of the ionosphere. The Radio Physics Laboratory, University of Calcutta, has also made some observations. Some observations have also been made at other physical laboratories.

(*f*) *Gravity observations.*—A large series of valuable gravity observations have been made by the Survey of India (and particularly by Dr. Graaf Hunter and Brig. Glennie). These observations gave most valuable information regarding the surface crust. The observations of the Survey of India, particularly the work of Sir Sydney Burrard, contributed largely to the conception of isostasy.

(*g*) *Marine surveys.*—In schemes for post-war marine surveys, meteorological observations, particularly of sea-temperature, salinity, ocean currents, etc., should have an important place. In the past, some important work in this direction has been done by the Zoological Survey of India.

2. *Post-war plan.*—The question of post-war plan for geophysical institutions was discussed by me and Dewan Bahadur Dr. K. R. Ramanathan at a meeting with Dr. Graaff Hunter and Brigadier Glennie of the Survey of India on 28th November 1945, and the following represents the tentative conclusions :—

(*a*) *Magnetic observatories.*—It is desirable that the Dehra Dun Magnetic Observatory should be revived and located at some suitable site at some distance from Dehra Dun, so as not to be disturbed by artificial electricity and that an observatory for recording earth-currents should also be associated with it. In view of the very great importance attached by the International Union of Geodesy and Geophysics to magnetic observations near the magnetic equator, that body passed a resolution recommending that the Government of India may start a magnetic observatory near Cape Comorin, which is very nearly on the magnetic equator. It is considered desirable that the magnetic observatory at Kodaikanal which is not far away from Cape Comorin should be revived or be transferred to a suitable site as near Cape Comorin as possible. Also, in consideration of the fact that the Government of Bombay has been pressing from time to time to take electricity to the Alibag town, which would interefere very seriously with this most important and one of the oldest observatories in the world, it is very desirable that the question of its transfer to some forest land in north Ratnagiri or near about should be considered. It will involve the question of setting up a duplicate observatory at that station for purpose of taking comparative observations for 2 or 3 years before the Alibag Observatory can be closed down so that the valuable Colaba and Alibag magnetic series covering a period of more than 100 years is not broken.

(*b*) *Seismological Observations.*—In view of the lapse of time since the Seismological Committee reported, it is desirable to review the scheme of seismological observations recommended by that Committee, and to report if any modification is required in that scheme.

(*c*) *Atmospheric electricity.*—The question whether the existing arrangement for observations of Atmospheric electricity is adequate or should be extended should be reviewed.

(*d*) *Observation of ionosphere.*—Plans are being made by the Radio Research Committee of the Council of Scientific and Industrial Research for the establishment of a Radio-Electronics Research Laboratory providing for the taking of detailed ionosphere observations. The question whether all ionosphere data required for geophysical studies could be obtained by collaboration with that institute should be reviewed.

(*e*) *Central Geophysical Institute.*—The question of setting up a Central Geophysical Institute with competent staff who will collect the geophysical data, make proper study of them and publish the results should also be considered. This institute should keep itself up-to-date with all the latest developments regarding instruments for geophysical research and geophysical prospecting, namely prospecting by magnetic, electrical, seismological and gravity methods and itself undertake research on such developments. The institute, it is considered, should be competent to give the necessary advice on all questions of prospecting by physical methods or to undertake such prospecting, if required.

3. As all the three departments are intimately concerned in geophysical work as detailed above, it is considered desirable that the Government of India should sanction the constitution of a Committee with the following members :—

1. Dr. Graaff Hunter } from the Survey of India ;
2. Brigadier Glennie }
3. Dr. H. Crookshank, Director, Geological Survey of India, and another officer of that Department to be selected by that Department ;
4. Dr. S. K. Banerji, Director General of Observatories ;
5. Dewan Bahadur Dr. K. R. Ramanathan, Officer on Special Duty, India Meteorological Department.

with directives (i) to prepare a post-war plan for geophysical work in India, (ii) financial implications and the responsibility and share of each department and (iii) methods of co-ordination of the work as a whole.

4. If the Department of Planning and Development would like to add a representative of that Department to this Committee, it is recommended that the services of Mr. Wadia, Mineralogical Adviser to the Government of India, may also be made available to the Committee.

5. It is understood that Brig. Glennie is likely to leave India sometime in March 1946 and Dr. Graaff Hunter may also not remain in India long. Both these officers have long experience of geophysical work in this country and it is most desirable that the services of these two officers be made available for drafting the post-war plan before they leave India. It is accordingly requested that the Government may be pleased to sanction the formation of this Committee at an early date. If Government agree to the formation of the above Committee, Brig. Glennie and Dr. Hunter agree that the meetings of the Committee should be held at Delhi in the 3rd or 4th week of January 1946. This will be arranged if the Director, Geological Survey of India has no objection to the proposal.

(Sd.) S. K. BANERJI,
Director General of Observatories.

सत्यमेव जयते

Department of Posts & Air, New Delhi (Mr. Zuberi).

DGO. UOI. No. XR24 dated, New Delhi, the 1st December 1945.

Copy to :—

(i) The Surveyor General of India, Temporary Secretariat Buildings, New Delhi.

(ii) The Director, Geological Survey of India, Chowringhee, Calcutta.

(Sd.) S. K. BANERJI,
Director General of Observatories.

DGO. UOI. No. XR24 dated, New Delhi, the 1st December 1945.

APPENDIX 2.

GOVERNMENT OF INDIA.

DEPARTMENT OF POSTS AND AIR.

No. 18-M/10-45. *Dated New Delhi, the 21st January 1945.*

FROM

MASARRAT HUSSAIN ZUBERI, ESQUIRE, *O.B.E., I.C.S.*
Deputy Secretary to the Government of India.

TO

THE DIRECTOR GENERAL OF OBSERVATORIES,
UPPER AIR OFFICE, LODHI ROAD,
New Delhi.

Subject.—PLAN FOR THE ORGANISATION OF GEOPHYSICAL INSTITUTIONS IN INDIA.

SIR,

I am directed to say that the Governor General in Council has been pleased to decide that a Committee consisting of the following gentlemen should be constituted in order to consider and report on the question of organising and developing in India institutions dealing with the study of Geophysics :—

(1) Professor M. N. Saha, F.R.S.	
(2) Dr. J. de Graaff Hunter	Survey of India.
(3) Brigadier E. A. Glennie	
(4) Dr. D. N. Wadia, Mineral Adviser, Planning and Development Department.	
(5) Dr. W. D. West	Geological Survey of India.
(6) Dr. G. Dessau	
(7) Dr. S. K. Banerji	India Meteorological Department.
(8) Diwan Bahadur Dr. K. R. Ramanathan	

The Governor General in Council is pleased to authorise you to convene such meetings of the Committee as are required for the purpose mentioned above.

I have the honour to be,
SIR,
Your most obedient servant,

(Sd.) M. H. ZUBERI,
Deputy Secretary to the Government of India.

APPENDIX 3.

VISITS TO GEOPHYSICAL STATIONS IN ENGLAND.

By D. N. WADIA.

1. *Visit to the Gravity Observation Station—Cirencester in the Cotswolds on the Upper Mesozoic rocks.*—Saw a Frost Gravimeter in working, noting small density differences, arising from composition, structural disposition and folding of rocks at different depths. A portable Frost Gravimeter was conveyed in a small Observation Van, which could take 8—10 readings of gravity from different stations, situated around a central check station in a few hours. The observations and computations were rapid, taking only a few minutes. The merits of the Frost Gravimeter are its compact size, simple construction, portability and ease of lowering and grounding the instrument from the van on to the road surface. The recording of gravity obtained at each selected observation point has to be checked with the original station. The reading at each station has first to be corrected for relative height difference ; even if these amount to a few feet, apart from topographical relief. When all topographic and relative altitude corrections are applied, readings of the Frost Gravimeter can be accurate to 1/10 of a milligal, (for most purposes, the readings required are only up to 1 milligal accuracy). These minor relative height differences need not be taken into account when only milligal readings are required.

2. *Demonstration of a captured German Gravimeter at the offices of the Anglo-Iranian Oil Co.*—This instrument was obviously of much elaborate and complicated construction, provided with various devices for checking interference from outside factors ; but it does not claim any greater efficiency or accuracy. Its principle was similar to the Frost Gravimeter and its portability was as easy.

3. *Visit to the Eakring Oilfied-20 miles from Newark, Nottinghamshire.*—This is the most productive of the four new oilfields recently brought into production in England. Their discovery was based solely on exploration of underground structures by gravity determination and their mapping by seismic reflection and refraction methods.

The productive oil horizon lies just below the Upper Carboniferous coal measures, overlying the Carboniferous limestone beds and Millstone grit. The actual reservoir-rock is a thin group of Millstone grit beds. It is over 2,000 ft. in depth below the surface composed of horizontal Triassic strata. Though the beds of Millstone grit form the reservoir-rocks from which all the Eakring oil is obtained, there is some doubt as to the actual source of the oil—whether it has not come by migration from some older Palaeozoic strata below. The structure, as revealed by seismic refraction mapping, is that of a low flat anticline, in the crest of which there are saturated pockets of Millstone grit (here a rather coarse and porous sandstone of variable thickness). There is but little of gas associated with the petroleum in this field and hence there are no " gushers " but all the oil has to be pumped. The petroleum is of good quality, rich in the lighter fractions. There are over 200 wells drilled on the Eakring anticline which produce, in the aggregate, about 100 tons of oil per day. The capacity of this field, however, has passed its peak and is slowly on the decline. It has produced over 300,000 tons of oil during war years. Further drilling is in progress to test deeper horizons.

Though indications of the presence of petroleum were well-known in this and adjoining areas in Nottinghamshire (in small springs and seapages of oil, associated with the coal measures and surface rocks), the geological structure of the area, hidden under the Upper-Carboniferous-Permian unconformity was not considered favourable and no serious oil prospecting was done. Geophysical methods revealed the unconformity and the structure contours of the favourable anticline, underlying it and the flat and featureless Triassic rocks of the area. The Eakring field is thus entirely the result of geophysical prospecting carried out by the Anglo-Iranian Oil Co. under the direction of G. M. Lees.

4. *Seismic refraction survey of the Formby oilfield, Liverpool.*—Professor Rankin of the Anglo-Iranian Oil Co. conducted a visit to this interesting field where some 8 tons of seapage oil a week flows out from pools in the surface, but whose source-rocks or their structure are hitherto not located. The rocks here are Upper-Triassic marls and sand-stones, overlying Carboniferous beds, covered at the surface under the peaty alluvium of the Mersey. A blast charge of 480 lbs. of dynamite was exploded in a 6″ bore-hole, specially drilled to a depth of 120 ft. The ground waves following the explosion were detected by six geophones, planted equidistantly along radii, 6 miles away from the charge. These were connected independently to a recording observation Van equipped with suitable apparatus. More or less clear seismographic recordings were obtained from each of the six detectors which were developed automatically in the Van and were ready for inspection in a few minutes.

The refracted seismic waves travelling back from an underground rock-surface, differing in composition, density and structure from the surrounding surface-rocks, would give some indication regarding its depth, contours and structural disposition. The interpretation of such seismographic recordings, however, is a matter which needs extreme care and accuracy.

The elimination of accidental ground vibrations at the series of geophones, at the time of exploding the charge, miles away from them, entails an elaborate system of radio-signalling and telephoning between them, the Observation Van and the Station Van exploding the charge.

APPENDIX 4.

BRIEF SUMMARY OF THE WORK DONE BY THE CARNEGIE INSTITUTION OF WASHINGTON—DEPARTMENT OF TERRESTRIAL MAGNETISM.

By K. R. RAMANATHAN.

A Department of Research in Terrestrial Magnetism was established under the auspices of the Carnegie Institution of Washington and work was begun on April 1, 1904. The object of the Department was to investigate " such problems of world-wide interest as relate to the magnetic and electric conditions of the earth and its atmosphere, not specifically the subject of inquiry of any one country, but of International concern and benefit". The plan of work embraced :

(*a*) A magnetic survey of ocean areas and unexplored regions.

(*b*) International observations of the variations.

(*c*) Observations in ocean depths and atmospheric regions.

> " The chief endeavour is to secure magnetic results in the regions most needed, and where there are no organisations prepared to undertake the work. Where magnetic surveys are in progress under competent direction, and when the prospects for early completion are favourable, the Department confines its work to the observations necessary for the proper correlation of results obtained with different instruments and by different methods."

In the period 1905 to 1926, observations were taken at 5,685 land stations of which 1,174 were in Africa, 1,163 in Asia and 972 in S. America. During 1921 to 1926 more attention was devoted to adding to the available information about the secular change in the magnetic elements. There is some evidence that the earth's intensity of magnetisation decreased at the large annual rate of 1/1500 of itself during the period 1840 to 1920. Secular variation has to be studied over the earth as a whole. The data now available show that the changes are not uniform over the earth but show regional variations connected with changes in the deeper layers of the oceans and continents. Continuous observations from *old* observatories are particularly valuable.

Organisation of Ocean Magnetic Observations is a special feature of the Carnegie Institution's work. This work is difficult and requires special designs for instruments, because observations have to be taken with swinging instruments, on a moving support. Data were obtained aboard the chartered brigantine the " Galilee " in the years 1905-1908 and aboard the specially constructed non-magnetic vessel the " Carnegie " during the years 1909-1929. Observations were taken in all oceans from 80°N to 60°S. Substantial assistance was given to the Norwegian Maud Expedition to the Arctic. The " Carnegie " was destroyed in November 1929 by an explosion. The British Admiralty is constructing a non-magnetic ship " Research."

The Carnegie Institution has improved old instruments and introduced many new instruments for making standardised observations in Terrestrial Magnetism. Examples of such instruments are :

C. I. W. Precision Coil Magnetometer, C. I. W. sine-galvanometer.

C. I. W. induction variometer (McNish).

The world-wide studies of the Carnegie Institution of Washington have revealed magnetic anomalies not only over land but also over oceans. Regions of observed magnetic anomalies are regions where more intensive geophysical studies are indicated.

In order to clarify further the purposes and aims of the Department of Terrestrial Magnetism, a conference was held in Washington on January 20, 1922 to determine what modifications, if any, in the original plan of work outlined in 1903 could be made then.

Main conclusions and recommendations of Conference

A. Magnetic and Electric Survey of the Earth.—(*a*) It was the consensus of opinion that the magnetic and electric survey of the Earth should be continued; however, in view of the satisfactory progress made since 1905, the future work need not be so intensive, but should be planned so as to obtain additional data in regions where urgently required, above all, as to the secular changes of the Earth's magnetism, which may play an important role in the theoretical solution of some of the outstanding problems. Detailed surveys of locally disturbed areas on land and sea may reveal suggestive relationships with gravity anomalies and geological formations.

(*b*) In view of the theoretical importance of magnetic and electric observations in upper levels of the atmosphere, it was considered highly desireable to make arrangements for such observations as soon as facilities and conditions permit.

B. Observatory work.—Because of the unsatisfactory distribution of magnetic observations in the Southern hemisphere, it was considered highly important that the complete programme of work in terrestrial magnetism, atmospheric electricity, earth-currents, and allied observations of the two magnetic observatories (Watheroo, Western Australia, and Huancayo, Peru) be fully carried out. Further relations with other geophysical and cosmical phenomena, such as polar lights, "statics", earth-currents, solar activity, etc., may be disclosed. The intensive study of instantaneous, or short period, perturbations at widely separated observatories, making use of available wireless stations for obtaining the desired accuracy in the time element, was specially recommended.

C. Laboratory Investigations.—It was thought essential that laboratory investigations be conducted concurrently with the observational work in the field and at the observatories. Besides the experiments on magnetism in general, now in progress, it was considered desirable to continue the investigations relating to the existence of vertical electric currents and the Earth's precise action on a magnet. The possible effect of high pressure on the critical temperature of magnetization was also considered a problem which may have important bearing on some of the topics.

D. Theoretical Studies.—The analysis and theoretical studies outlined under topic B, it was thought should be vigorously continued. It was suggested in this connection that it would be highly desirable to make provision, as soon as conditions permitted, to add to the Department's staff a well-trained mathematical physicist to assist the Director in his theoretical studies.

The observational data accummulated from land and ocean surveys were systematically worked out and analysed. Magneticians like Bartels and Chapman were invited to Washington as visiting professors to help in the analysis.

Realising that the daily and seasonal variations of the Earth's magnetic field and the variations associated with various types of magnetic disturbances had their origin in the upper atmosphere, the C. I. W., in accordance with the recommendations of the 1922 Conference, developed a section for the radio exploration of the ionosphere. In 1925, Breit and Tuve, working under the auspices of the C. I. W. suggested the now universally adopted radio-pulse-echo method of sounding the ionosphere and following up the suggestion step by step, Mr. Berkner developed the complete automatic multi-frequency reflection equipment which records the reflected pulses from the ionosphere over the whole range of frequencies 0·516 to 16 mc/sec. within an interval of 15 minutes. Such a unit was installed at the Huancayo magnetic observatory in 1937 and a similar one at the Watheroo Observatory in 1938. The records obtained with these instruments at these two observatories and at Washington have provided the most systematic and continuous ionospheric data that we posses and have contributed in great measure to our present knowledge of the ionosphere and its processes.

With a view to obtain a clue to the origin of the earth's internal field, laboratory work was started in collaboration with the Geophysical Laboratory of Washington on the magnetic properties of matter at high pressures and temperatures. Barnett's famous experiment on the magnetisation by rotation of ferromagnetic metals is one outcome of this activity. The construction of an Atomic Laboratory for studying atomic phenomena, in particular nuclear processes, with the installation of electrostatic generators, going first up to $1{\cdot}2\times10^6$ volts and later to 5 to 8×10^6 volts is another development in this direction. As Fleming says "Work in nuclear physics, dealing with fundamental conceptions of the nature and constitution of matter, must contribute further to the knowledge of the origin and to laws governing the complexities of the Earth's magnetic field so far found through the World Magnetic Survey."

APPENDIX 5.

GRAVITY WORK IN INDIA AND BURMA.

By J. DE GRAAFF HUNTER.

1. *19th Century.*—A few determinations by the Survey of India of gravity on the central meridian (77° 30′) from Cape Comorin to the Himalayas were made for specific purpose of determining the earth's ellipticity. Though vitiated by unforeseen errors due to instrumental causes (flexure of the stand) these began to indicate—as had also the astro observations for latitude—that the geoid was sensibly different from any spheriod.

20th Century.—(*a*) General gravity survey of the whole country was begun by the Survey of India about 1906, leading up to nearly 600 gravity stations over India and Burma by 1939. The interpretation of observed values has always been a matter of difficulty. The theory of isostasy which indeed derives from the Indian work, was much pressed by Hayford, Bowie of the U. S. A., who admitted that Burrard, lately Surveyor General of India, had opened the way for their work. Indian results, however, have not always fitted in with that theory and Glennie and myself have resisted the over-claims based on evidence found elsewhere. Glennie has done much to bring the matter into proper geological relationship.

(*b*) Work by Oil Companies in Bengal, Assam and Burma. It has been known to the Survey of India that gravity work with non-pendulum instruments has been in progress any time during the last 12 years. Particulars of the instruments and of their performance has been impossible to obtain in a precise form, and the instruments themselves have not been on the market. Only recently some discussion of the work done in Burma and E. India has been contributed by Evans and Crompton to the Mineral Research Symposium, which took place in Delhi in November 1945. It appears that some 6,000 gravity determinations have been made in this operation.

This puts the execution of gravimetric work in India and Burma well in line with anything done elsewhere, despite uninformed criticism to the contrary voiced at the Delhi Symposium. It does not, however, give much on which an independent assessment of the degree of reliability of the measures can be based, nor of instrumental details; both of which are required by any agency which carries out similar work. Nor does it make the instruments employed generally available.

2. *New Gravimeters.*—Since the end of the war, information concerning several gravimeters of American design has been received; and it has been possible to check the claims made by the makers. As a result, the Survey of India has taken steps to acquire a Frost Gravimeter. The Frost Gravimeter is a very convenient and portable, robust instrument of which some details given by the makers follow :

Weight 37 lbs.

Range (at one setting) 100 milligals.

Reading to 0·01 milligal.

Drift of order 0·1 milligal over hours/weeks, is said to be uniform.

Reading time : ½ minute.

Setting up is not elaborate, but no time is stated.

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3. *Appreciation.*—The pendulum work of the Survey of India 1906-1939 has provided a fairly complete picture of the gravity field in India and Burma. The researches of those concerned with it have contributed to the development of knowledge of the constitution of the earth's crust. The observational work, as that of similar contemporary work elsewhere, has been laborious. We are now to be equipped with an instrument, far more portable and rapid in use, while at the same time more than tenfold as precise—if we accept the testimony which has been received. It would appear that the pendulum is superseded and that its results are below the precision easily obtained by the new means.

The pendulums were believed free from variation, except as a rare or long drawn out occurrence; though closures with standards of other countries were disappointing in their amounts and difficult to account for. The new instruments have admitted "drift" which may become important in a considerable interval. It is necessary then to make certain stations as sub-standards of gravity which can be revisited as frequently as necessary, and so to control the drift. The higher accuracy of the new instrument makes the old gravity stations inadequate for this purpose, if used differentially. The precision of the pendulum results is sufficient to show up the considerable gravity anomalies of India, and, indeed, greater precision will not be immediately of value to geodesists. The end results depend not only on observation but on various hypotheses and corrections which are more in doubt than the observations. Higher precision has importance when much smaller areas than India as a whole are in question. As matters develop it will have importance in larger areas and provision for the future should be made.

Hitherto, so far as my knowledge goes, no change in the value of gravity at a station has ever been substantiated. Any change (of several milligals) in results by pendulums on reoccupying a station has been treated as due to pendulum changes. But if we could detect with certainty a change of 0·1 milligal at a station, it might be attributable to a change in height of the station of about 1 foot: and this might have a bearing on earthquake imminence or indicate slower changes of level as the case may be.

4. *Future Work.*—Modern transportation makes it possible for a modern gravimeter to be used at a base station, taken to a sub base station 1,000 miles away and used there, and the observations closed on the first station in a day or two; during which time we may hope instrumental drift will rarely attain 1 milligal and could be mostly cancelled. (My information is that the Frost Gravimeter drift never exceeded 0·1 milligal in two hours). We should be able to provide sub-standard g-stations over India without relative error anywhere exceeding 1 milligal: and relative values of adjacent sub-standards should be a good deal more precise. A programme of sub-standard gravity stations should be made. These should be located in relation to rapid inter-transit facilities—in other words they should be in the neighbourhood of air ports. Each of these would serve the surrounding area and be available for any local gravity observations, within rapid reach by ground transport. It is the Survey of India's intention to form a net of gravity stations at an average separation of 10 miles. These will be closed on sub-stations just alluded to. They will form reference points of all gravity work undertaken by Government or private agencies.

The objective of the former should not be exploitation of any particular area for commercial gain: but to cover the whole country systematically and lay bare those districts which are abnormal. Work of even greater detail should be done in selected areas to follow up the scientific side of crustal structure.

5. *Summary.*—To summarise the future gravity work, it is proposed :—

(i) To form sub-standard stations at air ports over India (Ceylon and Burma ?);

(ii) To make a 10-mile net work of gravity stations over India.

APPENDIX 6.

PROGRAMME FOR THE FROST GRAVIMETER.

By J. de Graaff Hunter.

1. It was stated in my note "Gravity work in India and Burma" which was distributed at the Committee meeting at Calcutta February 1946 that the Survey of India has taken steps to acquire a Frost Gravimeter. This is now in train and it is hoped the instrument may be received in time for use in the coming field season. If not, work now discussed will be correspondingly delayed.

2. In the final para of that note, it was proposed :—

(i) To form some sub-standard stations at air ports over India (Burma and Ceylon).

(ii) To make a 10-mile net work of gravity stations over India.

The use of (i) is apparent: but this need not be completed in the opening season. As regards (ii) the work should be done *after* the 10-mile AID marks have been duly built and fixed in position and height. As the work is only now commencing no such gravity work can be done in season 1946-47, in default of marked points.

3. The anticipated speed of work with the Frost Gravimeter is very great, and in forming a frame-work of gravity points at 10-mile intervals most of the time will be spent in transit. It is essential to choose locations served by motorable roads or routes, if full advantages are to be reaped. In that case, so far as determining gravity is concerned, a daily progress of 10 stations over a stretch of 100 miles is probably feasible. This quite outpaces the production of AID points: and there seems no occasion to provide for more than one Gravimeter to be in the field at one time. For security against breakdown, however, it has been proposed to acquire a second instrument of very similar design.

4. There are, however, complications if gravity work precedes the AID programme with which it has been proposed to associate it. The precision of the Gravimeter is believed to be

at least 0·1 milligal which is about the change in gravity corresponding to a height change of 1 foot. To service the gravity work to an adequate extent heights of this precision are wanted at all the gravity stations. An optimistic estimate of height error of heights determined (remote from lines of precise spirit levelling) from the standard 1″=1 mile maps of India is 10 feet: which corresponds to an error of one milligal in the reduced value of gravity.

It is also necessary to record the precise position of gravity stations by some permanent mark if the actual observed value is to have full significance. This need does not exist so far as determining the gravity field is concerned, *if* results were properly reduced for height: but arises if points for Gravimeter calibration are required. The marking of points in large numbers by pillars of sufficient durability has a good many difficulties—as Survey of India found with level Bench marks.

5. If, as may be reasonable, it is accepted that for geophysical purpose, gravity good to a few milligals is sufficient then the difficulties of para 4 mostly disappear. Such work, however, will not contribute to the intended 10-mile net work of g-stations contemplated as an all India framework: and has to be regarded on its geophysical value.

If a contrary view is held, then it becomes imperative to find a more satisfactory method of height determination of the gravity stations than has hitherto been available. Considerable thought has been given to this and some suggestions may be put to practical tests in the coming months.

6. Mr. Wadia has suggested that the southern fringe of the Deccan Trap should be gravimetrically explored by a strip of 15 miles width. Such a strip would involve greater difficulties of reduction for topography (compensated or not) and would actually require more consideration of the question of mode of compensation to be applied than would more compact blocks such as square degrees of latitude and longitude. The latter too would, it is thought, give much more useful information. It is suggested that rather than a continuous 15-mile strip it would be more useful to cover a number of discontinuous squares along the margin desired filling in gaps subsequently in view of results found, as it is deemed expedient.

To enable an appropriate programme to be framed a first requirement is a map on which the regions of interest geologically are clearly indicated by order of priority. Account of the motorable roads available would then be taken as this has an important bearing on the practical progress of the gravity work.

7. The Survey of India hope to cover (in a period of 20 years or more) the whole of India with the gravity 10-mile framework. It would naturally prefer that all work done contributed to that end. What has just been suggested would or would not do so according as a satisfactory heighting process can be evolved. In any case, the passing of a strong resolution by the Committee as to the urgent need for such gravity work would be an effective support. The Survey of India would then no doubt be also to apply its own resources to this work.

The personnel required is small and one Gravimeter plus one reserve is deemed sufficient. One or two motor vehicles would be needed. A five year period would suffice for the completion of what Mr. Wadia has roughly indicated. At the present stage, it does not seem feasible to be more specific in regard to details.

APPENDIX 7.

REPORT OF THE CONFERENCE CALLED TO FORMULATE PROPOSALS FOR A PROPER SEISMOLOGICAL ORGANISATION IN INDIA.

1. The Surveyor-General, the Director of the Geological Survey and the Director-General of Observatories met at 10-30 a.m. on 18th January 1936 and again on the 25th January at 12-30 p.m. in the Geological Survey Office, Calcutta, to discuss this subject.

2. In recent years India has had the unenviable distinction of being visited by a series of severe earthquakes which have naturally focussed attention on the fact that there is no branch of the public service exclusively devoted to the problem of seismological investigation. After each great earthquake officers of the Geological Department are deputed to the earthquake area to study the damage caused by the earthquake and its geological causes and effects; and a number of valuable Memoirs have appeared in the Geological Survey publications about these severe earthquakes. Seismographs were first installed in India about 40 years ago and as they are purely physical instruments and require daily attention by observers they were placed under the charge of the Meteorological Department which has fixed observatories at various centres in India and therefore was able to undertake the work without employment of extra staff. In the Geodetic Survey also there are geophysical measurements being made which bear a close

relationship to the problem of earthquakes. In none of the three departments, however, is the subject studied continuously; the smaller earthquake shocks receive little or no attention. There is no branch of the service nor any particular officer whose duty it is exclusively to study earthquake problems or to keep abreast with seismological research. In Japan the earthquake problem is recognised to be of vital importance because nearly the whole of the country lies within the seismic zone. There are over a hundred seismological observatories in Japan. Dr. Banerji, in his note of 1st August 1935, has pointed out that the Tokyo Imperial University has a special seismological department which maintains 25 seismological instruments of different types in continuous action in Tokyo itself. There is in Japan a large number of trained seismologists who work exclusively at seismological problems. The United States of America has over 40 seismological observatories at some of which there are scientists who devote themselves solely to seismological problems. In India, however, there are only 7 seismological observatories and no whole-time seismologist.

3. This Committee feels that the study of seismology requires encouragement in India. Steps should be taken to promote investigations on right lines. There should be someone whose duty it is to keep abreast with seismological work in other countries and efforts should be made to co-ordinate the work of the different departments where it concerns the earthquake problem. In the following paragraphs the institution of a seismological branch is recommended. Whether that will in time develop into a separate seismological institution with separate sections of its own, including one on types of buildings suitable for seismic areas, cannot be foreseen at present. The primary function of the proposed branch will be to gather information and collect records which will be of value in future investigations. The desirability of conducting investigations that will lead to accurate prediction of earthquakes has been mentioned on various occasions. This Committee feels that the chances of predicting beforehand the exact time and place of occurrence of large earthquakes are very small indeed. Earthquakes are the result of geological forces acting below the ground and we all know that the time-scale of geological action is very great compared with the time-scale of a human being. Dr. Dunn and Mr. Auden of the Geological Survey have pointed out that "An error in the time of prediction of a month or even a year would be insignificant geologically speaking but large from the point of view of the populace". Even if, however, there seems little likelihood of methods of prediction of earthquakes being evolved in the near future this Committee would repeat that the encouragement of seismological investigation by Government is very desirable. Both seismological and geological study can furnish results that are of value to builders in seismic regions. Government will always be faced with the problem of minimising the effects of earthquakes and this resolves itself very largely into the problem of erecting buildings that are resistant to earthquakes. The Earthquake Committee of the Geological Survey has recommended that new buildings within earthquake zones should be controlled by a Building Code as is done in Italy, Japan, California and New Zealand. The general principles of Building Codes adaptable to suit the conditions in the different provinces of India should be formulated by some Committee in India. It is suggested that, if the Chief Engineer, Central P. W. D., agrees on this point, the whole question of Building Codes for use in seismic zones in India might be referred to the Institute of Engineers (India) for report.

4. We shall proceed now to deal with the details of the seismological organisation considered to be required in India now. Our aim has been to suggest the minimum organisation required rather than to discuss the ideal seismological institution for a country of the size of India. At our meeting the installations at the existing seismological observatories in India were first reviewed and the records obtained from them during the Bihar Earthquakes of 1934 were recalled. It was concluded that the installations at existing observatories were inadequate and that more seismological observatories are required; in particular:—

(*a*) There are no vertical seismographs in India and it is recommended that these be installed at Bombay, Agra and Calcutta in order to supplement and complete the information now available at these stations from the horizontal components.

(*b*) The ordinary delicate seismographic installations efficiently record small local shocks and severe distant shocks, but may be knocked out of action by severe local shocks up to distances of 1,000 miles away from the epicentre. Their records need to be supplemented in the neighbourhood of seismic zones by records from instruments of a more robust type. Experimental equipment for the study of moderate or severe local shocks are now available. They are not yet fully satisfactory but are sufficiently so to make a start now with their installation in India. It is recommended that instruments of this type, strong-motion seismographs as they may be called, be installed at Calcutta, Agra and Dehra Dun.

(*c*) The single-component Omori Seismograph at Dehra Dun is of old type and should be supplemented by the more modern Milne-Shaw Seismograph, containing both north and east components.

(d) The single-component Milne-Shaw Seismographs at Calcutta and Agra should be completed by the other horizontal component.

5. The subject of new seismological observatories was fully considered. Attention was given to the new stations proposed by Dr. Banerji in August 1935 and those proposed by the Earthquake Committee of the Geological Survey. It was finally decided that the provision and maintenance of all the proposed seismographs would for the present involve Government in greater expense than this Conference feels justified in recommending, but it was recognised that as soon as the cost of seismographs of the strong-motion type can be cheapened and their maintenance cost lowered they should be installed at a number of other stations, *e.g.*, at Digboi in Assam, Yenangyaung in Burma and at a few Universities in northern India.

(*a*) The new stations and installations recommended are as follows :—

(i) Shillong (if adopted as H. Q. station) . .	Vertical seismograph, Milne-Shaw, both components. Strong-motion seismograph Tiltometer.
(ii) Patna, Lahore, Peshawar, Quetta . .	Milne-Shaw, both components. Strong-motion seismographs.
(iii) Allahabad, Maymyo	Milne-Shaw, single component. Strong-motion seismographs.
(iv) Monghyr (or Jamalpur)	Strong-motion seismograph.
(v) Karachi, Waltair	Milne-Shaw, single component.

For the maintenance of the installations at Patna, Lahore, Allahabad and Waltair it is proposed to seek the aid of the Universities. At Karachi Meteorological Office the work can probably be undertaken without extra staff, but the small meteorological offices at Peshawar and Quetta are considered by the Director General of Observatories to be understaffed and to require strengthening if seismological duties are added there. At Maymyo the work can be entrusted to the Survey of India and at Monghyr or Jamalpur it is hoped to be able to enlist the aid of the E. I. R. Engineering Department.

(*b*) At Srinagar it is understood that the Kashmir Government have already taken steps to establish a seismological observatory. At Khatmandu it is just possible that arrangements can be made to maintain a seismograph with the aid of staff employed by the British Envoy or the Legation Surgeon at Khatmandu ; if this should prove to be possible, the records from that station will be valuable.

6. It will not be possible to make efficient use of the records of all the proposed seismographs unless a separate seismological branch is simultaneously brought into being. We strongly recommend to Government that a seismological branch be formed with the following functions :—

(*a*) to deal exclusively with seismological investigations,

(*b*) to establish and maintain seismological observatories along the earthquake belt and elsewhere, as may be sanctioned from time to time,

(*c*) to collect seismograms from Indian Seismological stations and to tabulate them for the purpose of study and research and for publication, if necessary,

(*d*) to keep in touch with the latest developments in seismology in other countries.

Some of the problems which should receive the attention of the Officer-in-Charge of the branch have been stated by Dr. Banerji as follows :—

(i) Determination of the exact velocity and acceleration in epicentral regions. For the purpose of construction of earthquake resistant buildings, it is very important to know exactly the velocity and acceleration of ground movements in the epicentral regions of disastrous earthquakes. The methods at present employed for estimating the velocity and acceleration are rather rough. The Seismologist may arrange to determine these quantities more accurately by instrumental methods.

(ii) Determination of the distribution and frequency of earthquake shocks in the earthquake zones of India including study of the minor shocks that precede and follow major earthquakes.

(iii) Determination of the exact depths at which the earthquakes originate.

It is considered that some of the seismological stations and the headquarters office also should be so organised that they may act as mobile units immediately after an important earthquake in the Indian area.

7. It is obvious from the functions of the branch that the officer to be placed in charge of it should combine the basic training of a mathematical physicist with some skill in the handling and design of delicate physical instruments. It will be advantageous (but not wholly necessary) if he also happens before appointment to have specialised in geophysical problems and to have shown special ability therein. Shortly after appointment it will be desirable to depute the Officer to Japan for 3 or 4 months to see the seismological work being undertaken at Tokyo and elsewhere. In order to make the proposed new branch as self-contained as possible it is desirable that the Seismological Officer be assisted by a Class II officer, with somewhat similar qualifications, who will be able, it is hoped, to carry on the work of the branch during the absence of the Officer-in-Charge. The Officers should be assisted by 2 Senior Observers, 1 Junior Observer and 1 Clerk and 3 peons. The Junior Observer in additional to the staff originally proposed by Dr. Banerji in his note of 1st August 1935. This extra post is considered necessary on account of the additional seismological stations which are being recommended. There will be considerable tabulation work to be done at the seismological offices in connection with the records of these additional stations.

8. In order to achieve the double aim of co-ordinating the seismological work being carried on in the different departments of Government and of maintaining efficient liaison between these departments and the new proposed seismological branch it is recommended that the technical supervision of the seismological branch be entrusted to a Seismological Committee consisting of :—

(i) The Director, Geological Survey of India.

(ii) The Surveyor-General or the Director, Geodetic Branch, Survey of India.

(iii) The Director General of Observatories.

The Seismological Officer should submit his annual report as well as his programme of investigation for the following year to this Committee.

9. It is considered that the administrative control of the new seismological branch may, for the present, be placed under the Director General of Observatories. While seismology is essentially a science in which the geologists are most primarily interested, the Geological Survey of India does not possess the fixed observatories at which seismographs can be maintained. On the other hand, the Meteorological Department has an organisation of fixed observatories and is able to arrange for regular seismological observations without much difficulty and with a minimum of recurrent expenditure. Moreover, as the Seismologist to be placed in charge of the branch must necessarily be a physicist and a mathematician, the Meteorological Department is perhaps in the best position to supply leave substitutes if that becomes necessary from amongst the officers on its regular cadre. In England also it happens that seismological stations are at observatories under the charge of the Meteorological Office.

10. To supplement the purely seismological research to be carried out by the new organisation proposed above, geological and geophysical work is desirable. The former needs no special mention or extra funds, but the latter is likely to necessitate the purchase of special instruments of the magnetic variometer type for which an extra grant will be necessary. This branch of research will be carried out by the Geodetic Branch of the Survey of India and the Surveyor-General estimates that a sum of about Rs. 20,000 will be required for these instruments, which it will be difficult to find out of his grant for English stores.

11. Financial Requirements :—The schedules of estimated recurring and non-recurring costs are attached. The total non-recurring cost is estimated at Rs. 1,08,250, which will be spread over two or three years. The recurring cost is estimated at about Rs. 32,000 annually in the early years of the scheme and will rise to the average figure of Rs. 42,000 annually in course of time.

H. J. COUCHMAN, *Brigadier*,
Surveyor General of India.

A. M. HERON,
Director, Geological Survey of India.

C. W. B. NORMAND,
Director-General of Observatories.

SCHEDULE I TO SEISMOLOGICAL COMMITTEE'S REPORT.

Average Recurring Expenditure.

Paragraph.		Scale. Rs.	Annual average. Rs.
4 (*a*)	*Bombay, Agra, Calcutta*—		
	Photographic materials for vertical seismographs		750
(*b*)	*Calcutta, Agra, Dehra Dun*—		
	Charts for three strong-motion seismographs		450
(*c*)	*Dehra Dun*—		
	Charts for two Milne-Shaw seismographs		500
(*d*)	*Calcutta and Agra*—		
	Charts for two Milne-Shaw seismographs		500
5 (*a*) (i)	*Shillong*—		
	Seismologist	300—950	8,040
	Assistant Seismologist	200—600	4,992
	2 Senior Observers	70—160	2,832
	1 Junior Observer	40—100	864
	1 Clerk	40—100	864
	3 Peons	15	540
	Allowances, honoraria, etc.		2,000
	Supplies, services, contingencies, charts, photographic and other materials for experiments		4,000
	Other charges including rent of office		5,000
(ii)	*Patna*—		
	Allowance to Observes at University	40	480
	Charts, Photographic materials, etc.		700
	Lahore—	40	480
	(Same as Patna)		700
	Peshawar—		
	1 Senior Observer	70—160	1,416
	Charts, photographic materials, etc.		700
	Quetta—		
	(Same as Peshawar)	70—160	1,416
			700
(iii)	*Allahabad*—		
	Allowance to Observer at University	40	480
	Charts, photographic materials, etc.		450
	Maymyo—		
	Allowance to member of Survey of India staff	25	300
	Charts, photographic materials, etc.		450
(iv)	*Monghyr (or Jamalpur)*—		
	Allowance to Observer from Engineering Department of E. I. R. Jamalpur	20	240
	Charts, photographic materials, etc.		150
(v)	*Karachi*—		
	Work to be done by meteorological staff there (no allowance)	..	..
	Charts, photographic materials, etc.		250
	Waltair—		
	Allowance to observer at University	30	360
	Charts, photographic materials, etc.		250
5 (*b*)	*Khatmandu*—		
	Allowance to observer	20	240
	Charts, photographic materials, etc.		150
	TOTAL		41,244

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SCHEDULE II TO SEISMOLOGICAL COMMITTEE'S REPORT.

Non-Recurring Expenditure.

Paragraph.		Rs.	Rs.
4 (*a*)	*Bombay, Agra and Calcutta*—		
	3 Vertical seismographs	6,000	
(*b*)	*Calcutta, Agra and Dehra Dun*—		
	3 strong-motion seismographs	4,500	
(*c*)	*Dehra Dun*—		
	2 Milne-Shaw seismographs	3,000	
(*d*)	*Calcutta and Agra*—		
	2 Milne-Shaw seismographs	3,000	16,500
5 (*a*) (i)	*Shillong*—		
	Seismograph hut and installation	6,000	
	4 Seismographs	6,500	
	1 Tiltometer	1,900	
	1 Chronometer	850	
	1 Wireless receiver	300	
	1 Time-marking clock	200	15,750
(ii)	*Patna and Lahore*—		
	6 Seismographs	9,000	
	2 Chronometers	1,700	
	2 W/T receivers	600	
	2 Time-marking clocks	400	
			11,700
	Quetta and Peshawar—		
	6 Seismographs	9,000	
	2 Chronometers	1,700	
	2 W/T receivers	600	
	2 Time-marking clocks	400	
	2 Seismograph huts and installation	9,000	
			20,700
(iii)	*Allahabad*—		
	2 Seismographs	3,000	
	1 Chronometer	850	
	1 Time-marking clock	200	
			4,050
	Maymyo—		
	Hut for seismograph	4,000	
	2 Seismographs	3,000	
	1 W/T receiver	300	
	1 Time-marking clock	200	
	1 Chronometer	850	
			8,350
(iv)	*Monghyr (or Jamalpur)*—		
	Seismograph hut and installation	3,500	
	1 Seismograph	1,500	
	1 Chronometer	850	
	1 W/T receiver	300	
	1 Time-marking clock	200	
			6,350

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SCHEDULE II TO SEISMOLOGICAL COMMITTEE'S REPORT.

Paragraph.		Rs.	Rs.
5 (*a*)—*contd.*			
(v)	*Karachi and Waltair—*		
	2 Seismographs	3,000	
	2 W/T receivers	600	
	2 Time-marking clocks	400	
	1 Chronometer	850	
			4,850
10	*Geophysical Survey—*		
	2 sets of magnetic variometers	20,000	20,000
	TOTAL		1,08,250

APPENDIX 8

SCHEME FOR SEISMOLOGICAL OBSERVATORIES IN INDIA.

By DR. K. R. RAMANATHAN.

A Seismological Committee appointed by Government and consisting of the Surveyor-General (Brigadier H. J. Couchman), the Director of the Geological Survey of India (Dr. A. M. Heron) and the Director General of Observatories (Dr. C. W. B. Normand) submitted a report to Government in January 1936 reviewing the state of seismological organisation in India at that time and making definine recommendations for the formation of a Seismological Branch under the administrative control of the Director General of Observatories and the technical supervision of a Seismological Committee consisting of the Director, Geological Survey of India, the Surveyor-General and the Director General of Observatories. The report also gave an estimate of recurring and non-recurring costs—the former amounting to Rs. 42,000 a year and the latter to Rs. 1,08,250.

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The Government accepted the recommendations in principle but for financial reasons were not able to give effect to them.

In 1939, the Government agreed to create a post of " Special Officer for Seismological Research" temporarily for a period of 5 years in Central Services Class II of the India Meteorological Service and a Junior Clerk and a peon to help him—the funds to be met from the sanctioned budget of the India Meteorological Department.

In December 1943, the Government sanctioned the continuance of the post of Seismological Officer, a clerk and a peon for a further period of 5 years from 23rd November 1944.

In January 1946, the Government agreed to convert the post of Seismological Officer into that of a Seismologist in the cadre of Meteorologists in Indian Met. Service, Class I.

During these years, the collection of data from existing seismological observatories, their scrutiny and preparation for publication in the Seismological Bulletin have been going on. Some theoretical work has been done and also work on the development of a strong-motion seismograph. During the war years, instruments could not be got from abroad. The department was pre-occupied with more immediate items of work and the staff for the Seismological Section was totally inadequate and could not be supplemented.

The recommendations of 1936 Committee were with a view " to suggest the minimum organisation required rather than to discuss the ideal seismological institution for a country of the size of India." It is high time to implement the recommendations of the 1936 Committee with the following alterations and additions.

1. The staff proposed in 1936 for the Headquarters Office was :—

1 Seismologist, 1 Asstt. Seismologist, 2 Senior Observers,

1 Junior Observer, 1 Clerk and 3 Peons.

Considering that the work required of the Section will include :—

(1) Construction or Purchase of new instruments after preliminary correspondence with specialists abroad, their testing and installation;

(2) Maintenance, Supplies and Inspection;

(3) Training of Assistants and Observers at Outstations;

(4) Collection of records, their scrutiny and publication of Seismological Bulletin;

(5) Study, publication and experimental work;

(6) Liaison with officers of the Geological and Geodetic Surveys.

it is considered that the minimum Headquarters Staff should be :—

1 Seismologist (Class I)—already available.

1 Assistant Seismologist (Class II).

1 Inspector (of the grade of Professional Assistant) (Rs. 170-350).

2 Seismological Assistants (of the grade of Meteorological Assistants in the India Met. Dept. (Rs. 130-270)).

1 Senior Clerk.

1 Draftsman.

1 Typist.

1 Mechanic.

1 Laboratory Assistant and 3 Peons.

2. The estimated cost of non-recurring items—buildings and equipment—should be increased by a factor of 1·5 to 2. The India Met. Department should also revise the figures of recurring cost before submitting case to Government.

3. At least to start with, the Headquarters of the Seismologist should be at Poona where workshop and library facilities are available. (The difficulty at Delhi now is want of accommodation).

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4. The objectives of the Section should be :—

(*a*) Purchase, or better, construction of instruments, to measure the accelerations, periods and amplitudes of ground movement, in earthquake zones with a view to provide data for designing earthquake resistant buildings and structures.

(*b*) Organisation of seismographic observatories to determine the distribution and frequency of earthquake shocks in the earthquake zones including study of minor shocks that precede and follow major earthquakes.

(*c*) Determination of the depths of earthquakes and of the velocities of travel of earthquake waves at different depths in different regions.

(*d*) Study of microseisms associated with disturbed weather in Indian seas.

Special attention should be paid to the study of earth movements at sites of big dams like the Sukkur barrage in Sind, proposed dams across the Teesta and the Damodar dams.

5. The Section should aim at completing the present programme of development in *five* years from the date of sanction.

6. The priority for seismograph stations should be :—

Dehra Dun, Patna, Peshawar, Quetta, Karachi, Dibrugarh, Shillong.

For strong-motion instruments, dam sites in the Punjab, Khatmandu and Teesta Valley.

APPENDIX 9.

MEMORANDUM ON PLAN FOR A SEISMOLOGICAL STATION NETWORK IN INDIA WITH SPECIAL REFERENCE TO THE KOSI RIVER DAM PROJECT.

By THE U. S. COAST AND GEODETIC SURVEY, WASHINGTON.

Foreword.—Such a network, if developed along comprehensive lines, would involve the use of four types of seismographs; namely, (1) accelerographs or strong-motion seismographs to record ground movements of destructive magnitude, (2) high magnification seismographs to locate weak local shocks to detect and outline active fault zones, (3) intermediate type seismographs to locate moderate and strong shocks throughout the entire north India and Himalayan seismic belt, and (4) standard "Long-range" seismographs to operate in Central and Southern India. A brief description of each type with basic operating characteristics and approximate cost follows :—

I. Strong-Motion Seismographs.—(*a*) To operate only when automatically actuated by earthquake vibrations.

(*b*) The Coast and Geodetic Survey accelerograph used in California is described in Special Publications 201 and 206. Three components 3500 ca. Velocity and displacement curves for engineering research can be computed from the records by integration methods. See symposium entitiled "The Determination of True Ground Motion by Integration of Strong-Motion Records" in the Bulletin of the Seismological Society of America, January 1943.

(*c*) Coast and Geodetic Survey strong-motion seismograph. A new inexpensive type of instrument costing from $100 to $250 is now being designed by Coast and Geodetic Survey for wide distribution as a substitute for the Weed seismograph described in Special Publication 201. Recording will probably be on smoked paper, damping magnetic. Probable period 0·5. sec.; magnification 3.

II. High Sensitivity Seismographs for Recording Weak Local Shocks.—(*a*) To operate continuously on a 60 mm./min. time-scale.

(*b*) Benioff seismographs, galvanometric, horizontal and vertical components, record on paper or film. Pendulum period 1 sec. ; maximum magnification 100,000 ca. ; $5,000 ca. for 3 seismographs including recorders. For roughly $300, one component, preferably Z, can be made both sensitive and insensitive by operating a separate galvanometer through a shunt.

(*c*) Wood-Anderson seismographs, non-galvanometric, two horizontal components, photographic recording on paper. Pendulum periods 1 and 6 sec., magnifications 2,800 and 450 respectively ; $1,600 ca. for 2 seismographs including recorders.

(*d*) Sprengnether seismographs, small models, galvanometric, three components, photographic recording on paper. Short period ; magnification several thousands ; $4,000 ca. for 3 seismographs including recorders.

III.—Intermediate Type Seismographs for Location of Earthquakes, from 100 to 1,000 Miles Distant.—(*a*) To operate continuously on at least a 30 mm/min. time-scale, preferably 60 mm/min.

(*b*) Wood-Anderson seismographs two horizontal components, Pendulum period 6 sec. ; as listed in II (c).

Also, one vertical motion Benioff seismograph ; as listed in II (b). $3,100 ca. for 3 seismographs including recorders.

(*c*) Sprengnether seismographs, small models, 3 components ; as listed in II(d). Instruments period adjustable ; magnification 3,000 ca ; $4,000 ca. for 3 seismographs including recorders.

IV. Long-Period Standard Seismographs for Recording Distant Earthquakes.—(*a*) To operate continuously on 30 mm/min. time-scale.

(*b*) Sprengnether long-period seismographs, large models, galvanometric, three components, $5,000 ca. for seismographs and recorders.

(*c*) Other suitable types are the Wilip-Galitzin ; Milne-Shaw ; McComb-Romberg (non-tilt type) ; and Wood-Anderson Long period type as described in III (b).

V. Auxiliary Equipment.—Clock radio equipment and other accessories add about $600 to the cost of each station.

POLICY IN PLANNING STATIONS AND THEIR DISTRIBUTION.

Acceleration Measurements.—Accelerographs should be installed only in active seismic regions, preferably in cities which may be subject to destructive earthquakes. As the Kosi Dam may be considered in such a zone and conceivably subject to earthquakes as severe as those which struck Quetta in 1935, Bihar in 1934, Pegu, Burma in 1930, and Kangra in 1905, provision should be made for recording accelerations equal to the value of normal gravity or greater. Experience in California has shown that much higher accelerations are to be expected on river alluvium than on rock, and the recording capacity of the accelerograph should be adjusted accordingly. See page 33 or serial 672 for accelerograph sensitivities adopted in the Los Angeles, California area.

Several accelerographs should be installed within a radius of 25 or 50 miles of the Dam site including the site itself. The number of such instruments used over the active seismic areas of northern India will no doubt be controlled by economic considerations, but for engineering purposes a wide distribution is desirable. In California about twelve such instruments are located in San Francisco and a similar number in Los Angeles.

Engineers on the Pacific coast, realizing the need for a less expensive type of strong-motion seismograph, have recommended that such an instrument be designed by the Coast and Geodetic Survey and widely distributed in important seismic areas. The records obtained from accelerographs which are now costing $3,500 each (four times the cost in 1932) can be treated mathematically to obtain corresponding velocity and displacement curves and are thus susceptible to exhaustive analysis in the solution of engineering-seismological problems. The less costly instrument will not be suitable for such precise work but will nevertheless, give reliable data on the general magnitudes and periods of ground movements. In the proposed program for India, a satisfactory solution would likewise seem to be the acquisition of a few accelerographs of the high precision type and a rather broad distribution of a less expensive type.

Investigation of weak Local Shocks at Dam and Elsewhere.—The instruments listed under II are intended for the precise location of weak and often unfelt shocks in active seismic areas which need to be investigated for engineering or other purposes. At least three stations should be established in and around the area to be intensively studied. It may be expected that after several years of operation (to determine the regional travel-time characteristics) local shocks may be located within approximately a kilometer. In southern California it is felt that such a network has made it possible to associate the majority of earthquakes with known fault systems or has revealed hidden faults. The stations should not be more than 200 miles, preferably about 50 miles, from the area under investigation. In the Boulder Dam area three stations were established in the pattern of a triangle roughly 40 miles on a side, but later it was felt that grouping them closer to the Dam might have been more effective. A network of this general character is suggested for the Kosi Dam area or any other active area in which engineering and economic considerations seem to justify the cost. In the United States three areas are under such instrumental control—San Francisco, Los Angeles, and Boulder Dam. See Seismic Investigations in the Boulder Dam Area, 1940-44 by D. S. Carder in the Bulletin of the Seismological Society of America, October 1945.

Location of Earthquakes in Extensive Seismic Areas.—The seismic zone of the Himalayas and northern India is one which seems to require a chain of intermediate type seismographs mainly outside its southern boundary to obtain adequate seismographic control. The instruments suggested in III seem to satisfy requirements inasmuch as their most effective range is from 100 to 1,000 miles. A group of perhaps five stations stretching from the general region of Calcutta to Karachi would be ideal except for the desirability of having at least a few stations in the far north, for example, at Lahore. Existing stations at Agra, Alipore, and Dehra Dun would provide excellent starting points for such a network if modern instruments were installed.

One of the most effective instrumental combinations for this type of program consists of two Wood-Anderson horizontal seismographs and one vertical-motion Benioff as indicated in III (*b*). If funds for the India program are limited and only one type of station set-up were considered practicable to cover all needs, this particular grouping would serve fairly well as a substitute for the Benioff instruments suggested in the investigation of weak local shocks, and for the long-range seismographs discussed in the following paragraphs. The operation of only one vertical component Benioff seismograph has been suggested on good authority as quite an effective installation for auxiliary stations but this sensitive instrument requires careful handling.

Location of Distant Earthquakes.—Instruments for such work constitute the standard type of seismograph found at most stations. They are intended for the recording of earthquakes occurring anywhere in the world. Inasmuch as a basic objective in planning a world network of stations is to obtain uniform distribution, a station or two of this type in southern India would serve this purpose and furnish valuable data on earthquakes in the seismic zones of northern India.

In order to study the mechanics of a destructive earthquake, seismologists utilize not only the records obtained in the immediate region of the earthquake but also those obtained all over the globe. The travel-time curve which forms the basis of all seismological studies relating to regional variations in crustal structure would not be complete for a major earthquake in northern India unless satisfactory data from central and southern India were available. Milne-Shaw seismographs now operating in India serve this purpose to a limited extent but some instruments of higher magnification should also be operated. At stations where instruments now considered obsolete are operated, every effort should be made to recondition them to obtain satisfactory records of a major shock should one occur, especially with reference to time control. The importance of precise time is evident when it is considered that the most important seismic waves travel over the surface of the earth at speeds of 10 and 15 miles per second.

THE ENGINEERING PROBLEM.

In the absence of authentic data on destructive earthquake movements engineers have for many years resorted to the use of a hypothetical ground wave to compute probable stresses in engineering structures induced by earthquakes. This is a sinusoidal wave of 1 inch single amplitude, 1 second period, and 0·1 gravity acceleration. The purpose of collecting instrumental data on destructive motions is primarily to improve on this hypothetical formula but up to the present time the data have been too meagre to arrive at any definite conclusions, and the application of the data to practical problems is technically difficult.

In recent years the Coast and Geodetic Survey has compiled data in the form of period-amplitude graphs but all of these have not yet been published. See MSS-9, Analysis of the El Centre Accelerograph Record of the Imperial Valley Earthquake of May 18, 1940, and Period-Amplitude Analyses of Strong-Motion Records in the 1944 Transactions of the American Geophysical Union, Part II, pp. 290-294. Engineers are interested primarily in the results obtained from only a very few major shocks rather than in the many records of moderate which are recorded. Much data, however, have been subjected to critical theoretical and laboratory treatment. One of the recent advances in this field has been the development of the torsion pendulum analyser which performs a computation yielding the resulting motion of a given structure when subjected to a known ground motion. This apparatus is described in detail by M. A. Biot in the April 1941 number of the Bulletin of the Seismological Society of America and again in the Transactions of the American Society of Civil Engineers for October 1943.

As the primary need of the engineer is to know what maximum motions to expect in a destructive earthquake, the establishment of a chain of strong-motion stations in the northern India seismic zone will be an invaluable contribution. Up to the present the analysis of the Imperial Valley earthquake record obtained at El Centre in 1940 is perhaps the most comprehensive yet made but its application to practical engineering problems still affords an opportunity for further theoretical and laboratory research. It will be noted in MSS-9 that the maximum acceleration almost reaches 0·4 gravity instead of 0·1 gravity as generally used in designing earthquake-resistant structures but this high value is for high frequency waves of extremely small displacement. Note too that the Imperial Valley earthquake was by no means a major disturbance.

APPENDIX 10.

TERRESTRIAL MAGNETISM WORK IN INDIA AND BURMA.

By J. DE GRAAFF HUNTER.

1. A systematic magnetic survey of India was commenced by the Survey of India early in the 20th century. The following note refers almost exclusively to this and to proposed future work by the same agency. The much longer history of Colaba/Alibag observatory is properly dealt with by Dr. Banerji: results obtained there, were made available in support of the general survey.

Several observatories were set up and maintained for considerable periods as shown in the following table. They were originally intended to serve for the proper reduction of field observations for which—owing to the large area to be covered—a single observatory was no deemed adequate :

Magnetic Observatories of the Survey of India.

	Period of operation.	
	Opened.	Closed.
Dehra Dun	1902	1943
Barrackpore	1903	1915
Toungoo	1904	1923
Kodaikanal	1902	1923

Field observations commenced in 1901 and were mostly completed by 1913. In all 1,399 stations were occupied. There were in addition 80 Repeat Stations.

Some regions where anomalies had been revealed were further investigated with negative results (pp. 20, 21 of " Records of the Survey of India, Vol. XIX ").

2. *1914 Committee.*—In 1914 Government constituted a Committee " to consider the present position of the Magnetic Survey and advise as to the steps to be taken to complete it " The Committee consisted of—

President.—Dr. G. T. WALKER, C.S.I., Sc.D., F.R.S.

Members.—CAPTAIN H. H. THOMAS, R.E.
MR. J. DE GRAAFF HUNTER, M.A.

It submitted its report in March 1914.

3. *Results.*—World war I prevented the early implementing of the recommendations. Finally in 1925 results of the magnetic survey were published in Records of the Survey of India, Vol. XIX; The Magnetic Survey of India, 1901-20.

4. *Later History.*—(*a*) *Observatories* : The subsequent history of the magnetic Survey up to 1930 is mostly indicated by the table in section 1. Barrackpore Observatory was deemed, redundant for the post field survey period by the 1914 Committee and was closed in 1915. Toungoo and Kodaikanal observatories were closed in 1923 : after which Dehra Dun (+Colaba) observatory alone continued in operation until 1943. At that time the flooding of the underground observatory and encroachment of buildings essential for war purposes led to the closing of the Dehra Dun observatory and its subsequent condemnation. As magnetic observations could no longer be conducted there satisfactorily, it was decided to discontinue them entirely and to consider after the war the establishment of a better observatory at an undisturbed site.

The 1914 Committee had stressed the value of maintaining a few observatories rather than the periodic reoccupation of Repeat Stations : considering that their objective was scientific rather than economic. It considered that Barrackpore Observatory could be dismantled (which was promptly done) and that the 3 remaining observatories with Colaba would meet future needs. It contemplated a second magnetic survey in 1935 or 1946, years of sunspot minima. The Repeat Stations were not further reoccupied : but in 1923, on financial grounds which overrode other considerations, Kodaikanal and Toungoo observatories were closed. Only Dehra Dun and Colaba were in operation after 1923.

(*b*) *Field observations.*—With only two observatories in operation and no reoccupation of Repeat Stations, the situation naturally deteriorated. It became impossible to assess secular change of declination even adequately for statement of declinations printed on Survey of India maps. About 1930 an attempt was made to recover the situation and 37 Repeat Stations in NW and Central India (reasonably covered by Dehra Dun and Colaba Observatories) were reoccupied : at the same time it was proposed to reopen Kodaikanal and Toungoo observatories in time for the following field season. Again financial considerations intervened and the observatories were not reopened : and no further work on Repeat Stations was done.

In 1943, the situation, which obviously had become far worse, was such that doubts exceeding one degree as to the values of declination existed. Obviously Burma Repeat Stations could not be reoccupied, but a number of those on a line from Assam to Ceylon were occupied (for declination only) in 1943 for military reasons. Since then all other Repeat Stations have been reoccupied and observations for declination, dip and horizontal force have been taken. The results are of lower precision than what was formerly achieved in that full correction for diurnal change and minor disturbances could not be made, lacking observatory cover. They served however to allow reliable isogonic lines to be drawn and brought to epoch 1942. The results were published in War Research Pamphlet No. 6. Further field work is still in progress.

5. ***Future Work.***—It is now for consideration what the future policy should be as regards magnetic survey.

Since 1914, the balance between scientific and economic objectives has undoubtedly shifted. From a scientific point of view, it is desirable to reopen at least Dehra Dun and Kodaikanal observatories or alternatives to them. I understand that the observatory at Kodaikanal, transferred to the Director, Solar Physics Observatory in 1916 and closed in 1923, still exists. That of Dehra Dun is no longer available and is under orders of demolition. It has been suggested that a new observatory should be constructed in Dehra Dun district outside the range of electrical developments and that with it should be associated earth current measurements. A site, which I believe, will serve both purposes has been provisionally selected after enquiries made as to the anticipated electrical developments in the neighbourhood. Situated some 15 miles from Dehra Dun, it is reasonably accessible, which would permit personnel employed to keep in touch with wider scientific activities at Dehra.

Kodaikanal (latitude 10°·2, longitude 77°·5) lies some 70 miles north of agonic line (zero dip) which passes close to the southern tip of India. There seem advantages in using the old observatory rather than building a new one elsewhere.

From the Survey of India point of view, and I think also for geophysical reasons, there is good reason for a regular programme of reoccupation of the Repeat Stations at intervals of 5 years. To my mind they give the secular changes, required particularly for keeping declination up-to-date, more practically and completely than can be derived from a limited number of observatories. The information is of increasing importance for aerial navigation. Indeed for such reasons I consider that additional Repeat Stations should be created and maintained outside the land boundaries of India in collaboration with other external agencies. A limited number of well chosen Repeat Stations will serve to keep up-to-date all land and maritime magnetic survey. I have recent experience of the opposite situation.

6. *Conclusion.*—I consider that the following should be included in the programme for future magnetic work :—

(*a*) Observatories at Dehra Dun and Kodaikanal or alternative sites.

(*b*) Quinquennial occupation of existing Repeat Stations of old magnetic survey.

(*c*) Quinquennial occupation of additional Repeat Stations external to India as may be arranged.

APPENDIX 11.

SCHEME FOR MAGNETIC, EARTH CURRENT AND COSMIC RAY OBSERVATORIES IN INDIA.

By Dr. K. R. Ramanathan.

At present there is only one Magnetic Observatory in India, at Alibag, maintaining continuous registration of Terrestrial Magnetic Elements. The Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics at its meeting in Lisbon in 1933 recommended the re-starting of a magnetic observatory in the neighbourhood of Cape Comorin in the extreme South of India in view of its proximity to the magnetic equator. The nearest magnetic observatories outside India are Tashkent in U. S. S. R., Hongkong in China and Batavia in Java, of which the last two places stopped functioning in the last few war years. In view of the range of latitude covered by India 8°N to 36°N, it is considered desirable that there should be at least 3 magnetic observatories in India—one in South India near the magnetic equator, one at Alibag or its neighbourhood (if Alibag has to be closed down due to threat of artificial disturbances) and one nearabout Dehra Dun.

2. It is important that the sites for magnetic observatories should be so chosen that artificial disturbances from electric current or from structures with iron in them are not likely to affect the records for many years to come. In view of the fact that variations in the earth's magnetic field, natural earth currents, and cosmic ray intensities are highly correlated, it is desirable that areas for continuous registration of earth current and cosmic rays should be set up at the magnetic observatories. It may also be convenient to make observations of atmospheric electricity at the same place. The observatories therefore should be built within a large enclosed area, say of about 100 acres, and that they should be in a reserved forest through which electric power

lines will not be taken. After fixing the areas in cooperation with the provincial authorities, efforts should be made to secure the inviolability of these specially reserved areas by legislation, if necessary. Naturally, quarters will have to be built for the staff working in the observatories.

3. One of the three proposed Magnetic, Earth Current and Cosmic Ray observatories should act as a Central Geophysical Observatory for testing and standardising instruments and making arrangements for their inter-comparison, etc. It is proposed that the Magnetic Observatory at Bombay (Alibag) or its successor should undertake this function. Testing of magnetic compasses for ships may have also to be undertaken in the future.

4. Repeat stations for magnetic secular variation work should, as far as possible, be in places where structures with magnetic material in them are not likely to grow up in their neighbourhood. In its 1939 meeting, the Association for Terrestrial Magnetism and Electricity emphasised the desirability of determining, by observations at special repeat stations, to what extent great local anomalies of the Earth's magnetic field were reflected in the secular change.

5. *Equipment for Magnetic, Earth Current, Cosmic Ray and Atmospheric Electric Observatories.*—The primary function of a magnetic observatory is to obtain continuous records of all the magnetic elements (D, H and Z or X, Y and Z) for which the magnitudes and times of variations and the earth's field can be determined. The records have to be correlated with absolute observations at regular intervals and there should be regular programmes of observations, test, standardisation and reduction and publication in standard form.

A.—*Additional equipment for Central Geophysical Observatory*—

Magnetic instruments—

(i) La Cour quick-run magnetographs and recorders and standardising coils.
(ii) Schuster-Smith coil Magnetometer for measuring H including potentiometer, standard cells, galvanometer, etc.
(iii) (C. I. W.) Astatic magnetometer for the testing of materials for feeble magnetisation.
(iv) Two La Cour quartz-fibre horizontal magnetometers mounted on theodolite base. (Q. H. M.).
(v) One Askania Schmidt Z Field Variometer.

Estimated cost Rs. 40,000.

Cosmic Ray Meters—

Two Compton Bennett precision recording Cosmic Ray Meters.

Equipment for Earth Current Work—
Leeds and Northrup or Cambridge multiple-point recorder—installation of 2 miles length of lines. Other electrical equipment.

Atmospheric Electricity Work—
Electrometers (Quadrant, Unifilar, Bifilar).
Ionior Collectors.
Recording Conductivity apparatus.
Recorders.
Calibrating condensers.
Cathode-Ray Oscillographs.
Ion-Counters (small, intermediate and large).
Nuclei counters.
Valves and wireless apparatus.

Estimated cost Rs. 50,000.

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B.—*Equipment for new Magnetic and Earth Current observatories*—

Theodolite Magnetometer for absolute measurements of D and H.

Earth-Inductor with galvanometer.
2 Chronometers.
1 Clock and 1 W/T Receiver.
Recording variometers for H, D and Z with time marking clocks.
1 Horizontal variometer (for eye-reading).
Earth-current set up with galvn. resistance, lines, etc.

Estimated cost Rs. 60,000.

C.—*Equipment for new Atmospheric Electric Observatories*—

Continuous measurements are required of—

Potential Gradient.
Positive and Negative conductivities.
No. of small, intermediate and large ions.
Rate of production of ions.
Point discharge currents.
Equipment for special studies.

Estimated cost Rs. 40,000

Buildings for Magnetic and Earth Current Observatories.—

- (*a*) Absolute observation building.
- (*b*) Variometer building.
- (*c*) Office building, records, laboratory and dark room.
- (*d*) Quarters for 1 Officer, 4 Assistants, 3 Peons.
- (*e*) Atmospheric Electricity.
- (*f*) Meteorological instruments installation.

APPENDIX 12.

NOTE ON EARTH-CURRENTS.

By Dr. K. R. RAMANATHAN.

1. Earth currents are currents flowing between neutral electrodes embedded in the earth and not caused by man-made power-systems. They may be :—

(1) mainly local, caused by chemical processes, temperature differences, ocean-tides etc., or

(2) part of a world-wide system, showing correlations with other world-wide phenomena like changes in the earth's magnetic field and aurorae.

Leakage from electric power systems, especially earthed D. C. systems, can mask the currents due to natural causes. The magnetic observatories at Greenwich, Paris, Bombay and Copenhagen had to be shifted due to the magnetic effects of leakage currents from neighbouring electric railways.

The modern tendency is to use duplicate electrodes and measure currents in both N-S and E-W directions. Either galvanometers or potentiometers are used to measure earth-potentials. World-wide "earth-currents" alternate in direction during the day.

2. Systematic continuous registration of earth currents have been made for purely scientific purposes at :—

Greenwich	1865-67.
Berlin	1883-91.
Paris	Early nineties.
Ebro (Spain)	1910.
Watheroo (Australia)	1923.
Huancayo (Peru)	1926.
Tucson (Arisona)	1931.

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Measurements for short periods have also been made at a number of Polar Stations and at Colaba and Alibag, Bombay.

3. The available data of daily variations show the existence of a system of current whorls inside the earth, spaced symmetrically with respect to the equator and moving round with the sun. The whorls on the sunlit side of the earth are more pronounced (Gish).

Earth-current "storms" occur associated with magnetic storms. As in the case of the latter, the amplitudes of the disturbances are larger at high latitudes than at middle or low latitudes.

There is no doubt that there is a high correlation between the variations in earth-currents and the magnetic variations. Both are due to the effect of electric currents circulating in the upper conducting atmosphere. The detailed inter-relations between the two have yet to be worked out.

For this, we want data.

4. The phenomenon of earth-currents is complicated. It is affected by the stratification of the sub-soil with respect to conductivity and the distribution of land and sea with their enormous differences in conductivity and "skin-effect". The number of observatories regularly recording earth-currents are very few. The paucity of observations is greatest in low latitudes.

As Rooney has said, "The fragmentary character of the observations has been a real handicap to the investigation of earth currents, particularly since no single observations can be secured which are entirely free from the masking effect of extraneous potentials such as those due to electrochemical action. More widely distributed observatories would do much to clear up the uncertainties and misapprehensions arising at times from this source and when considered in connection with magnetic records and with the enlightening data now made available by the recently developed technique for investigation of the ionosphere, should lead to a far better understanding, not only of earth-currents but of other allied phenomena as well".

5. With the large range of latitudes that India covers, it would be of great *scientific* value to maintain continuous registrations of earth-currents in *at least* two places, one in South India near the magnetic equator and another in North India in the Indo-Gangetic alluvium of the Punjab or west U. P. A third registration station near the magnetic observatory at Alibag is also greatly to be desired.

APPENDIX 13.

MAGNETIC PROGRAMME.

By MR. B. L. GULATEE.

1. There are 67 Repeat Stations in India, 12 Repeat Stations in Burma and 1 in Andamans. The Indian Stations have all been visited from 1943 to 1945, but owing to non-existence of observatories, the results have not been reduced with full refinements. Stations depending on Alibag and Dehra were reduced for Alibag alone and others were not reduced at all.

It is no use observing now or even a year hence, because the S. V. deduced from such a short period will be burdened with considerable error. Energies must first be directed to rehabilitation of the older observatories.

2. Arguments for enhanced magnetic activity are given in the attached note. The continuous magnetic work at Dehra was stopped from 18th August 1943, and the absolute work from October 1943. The absolute houses as well as the underground observatory have been demolished and their site is entirely useless as there is a considerable amount of iron round about due to the buildings erected during war.

Previously the absolute work consisted of:—

Declination—thrice a week; H. F.—thrice a week; Dip—daily.

3. A visit to the Repeat Stations during 1943-45 revealed that the sites of some of them were becoming useless for magnetic observations due to construction of buildings containing iron and the proximity of habitated areas. In order not to *lose the continuity of our magnetic work*, it was decided to select fresh suitable sites after taking simultaneous comparative observations at both the old and new ones. There were 23 such stations out of which 16 were observed last year and 7 will be observed this year. Actually the continuity has been broken already in 2 respects:—

(*a*) By discontinuance of continuous magnetic observatories.

(*b*) By lack of observations at Repeat Stations in intervening years resulting in ignorance of S. V. for these years. Hence rate of variation of S. V. cannot be determined. Nothing was done till 1931, when about half of India was done—being the portion deemed to be covered by Dehra and Colaba Observatories, the rest being deferred till Kodaikanal and Toungoo were reopened. After that nothing until 1942-44, when we visited all Repeat Stations except Burma.

APPENDIX 14.

SECULAR VARIATION OF MAGNETIC DECLINATION[*] IN INDIA.

By B. L. GULATEE.

There are several physical phenomena which are ostensibly constant but are suspected of being burdened with small secular variations. These suspected changes are usually of the same order of magnitude as the probable errors of their determination and the variations found are often spurious and are traceable to the uncertainty of observations or apparatus. Instances of such phenomena are—Value of gravity at a place, heights of mountain peaks, continental drift, relative fluctuations of land and sea, etc. The magnetic field of the earth differs from the above in two respects: (i) the magnetic elements are changing all the time, and (ii) the secular change is indubitable and is large. Its delineation, however, is not easy as the following would show. We shall confine ourselves to a consideration of the magnetic declination alone.

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[*] Many countries now use the term "Magnetic Variation" for "Magnetic Declination".

The information about magnetic declination in a country is usually displayed in the form of generalised charts which give lines of equal magnetic declination (Isogonic lines) at a given epoch and also lines of equal annual change (Isoporic lines). These latter enable the isogonal lines to be drawn for succeeding epochs. No civilised country can do without such charts, as they are indispensable for land and hydrographic survey as well as for nautical and aeronautical purposes. For the initial drawing of Isogonal charts, a general magnetic survey of an elaborate nature is necessary. For India, this survey comprised observations at 1,400 field stations and 5 permanent magnetic observatories equipped with continuously recording magnetographs. The field work was carried out between 1901 and 1913 and isogonals were drawn for each epoch 1909·0 after correcting the field observations for diurnal variation, disturbance and secular variations. An important point about these corrections is, that while diurnal variation and disturbance at a station can be interpolated sufficiently accurately from the data of fixed observatories which are necessarily a considerable distance apart, the correction for secular variation changes rapidly from place to place, necessitating the supplementing of fixed observatories by a certain number of repeat stations. Apart from the question of funds available, various other factors must be taken into account in deciding upon the number of Repeat Stations and the interval between their successive reoccupation. A short period of 2 or 3 years is open to the objection that errors of measurement would have a large effect on the derived rate of change, while the adoption of as long a period as 11 years (corresponding to that of sunspot cycle) involves the risk of certain features of the change being skipped over. From the data provided by the observatories, it appears that secular changes, though not uniformly progressive, can be satisfactorily expressed by straight lines or smooth curves over a period of about 5 or 6 years, after which a break occurs in the type of the curve. This is exemplified by Chart I (at end of brochure), in which mean annual values of declination at Dehra Dun and Alibag have been plotted against time. The two curves are of the same pattern and point to the existence of short period fluctuations. For any detailed examination, however, it is necessary to plot the monthly values, which, of course are only available at fixed observatories. Five years is now universally accepted as the interval at which repeat stations should be revisited.

Chart II (at end of brochure) shows the Isoporic lines or lines of equal annual change of declination in India derived from intervals 1909-15, 1915-20, 1920-31 and 1931-46.

A study of these isopors even though they cover a short period reveals some interesting facts. The isoporic lines for the intervals 1909-15 and 1915-20 are nearly parallel to each other, there being a simple westerly shift of about 1½ minutes. The isopors in 1920-31 have a tendency to swing in a north westerly direction, but this shift does not appear to have been maintained, the 1931-46 curves swinging back to resume their older shape.

A more interesting and important feature, however, is that in India which is an area of negative change, these curves do not form closed loops, *i.e.* there is no focus of rapid change at present. The focus of negative change is down to the south in the Indian Ocean (beyond the range of Chart II). The nearest focus of positive change is in west Australia. This focus appears to be moving continuously westwards and if the westerly shift of the isopors is maintained, it may soon find its way in India. It is, however, not certain as to how long this westerly movement is likely to continue. It is not improbable that this westerly shift may at some time reach its maximum and then swing back ultimately changing over to an easterly movement. If this happens, this will be an event of no small interest.

To keep secular variation up-to-date after the general magnetic survey of India was completed, it was decided (*a*) to visit quinquennially 80 stations (called Repeat Stations) of the original survey and (*b*) to maintain continuous observatories at Dehra Dun, Kodaikanal, Toungoo and Alibag. These observatories have to be kept running to correct 5 yearly observations at Repeat Stations for diurnal variation and disturbances, which are at times as much as four times the annual secular change.

Even with this programme, however, it is not easy to delineate real changes in secular variation pattern, because observed values at repeat stations have to be given certain corrections to reduce them to the mean of months and these reductions are burdened with uncertainties which are of the same order of magnitude as real changes of secular variation. Hence also the necessity of selecting repeat stations at places free from natural or artificial disturbances. The changes sought are so small that any such extraneous disturbances can introduce considerable uncertainties and enhance the difficulties of the task.

Elaborate work of this nature, with no obvious return for the money spent, is liable to risk of uninformed criticism from the top. Owing to financial stringency two of the observatories were shut down in 1923, and during the war the Dehra Dun underground observatory was put out of action on account of its being flooded. No systematic 5-yearly observations at Repeat Stations were carried out either.

The practical effect of this was felt during this war, when declinations had to be put on topographical maps for military purposes. Secular variations had to be extrapolated over a period of 20 years and the situation had deteriorated so far that doubts exceeding 1° regarding the value of declination existed in some parts. In regions where the variation is greater than that in India, the situation can be worse. The case of Cocos Island near Andamans affords a good example. Isogonals on the Australian aeronautical series of charts published by the Property and Survey Branch, Department of Interior, Canberra, showed the value of magnetic declination at Cocos Island in 1942 to be 5½°W. The Chief Geophysicist, Canberra, reported that this value could not be far wrong, inspite of observations being 20 years old, as the values of secular variation had been assessed very carefully. In point of fact, however, observations in 1946 by Messrs. Chamberlain and McMarthy have shown the accepted value to be in error by as much as 3°. Considerable discrepancies exist between the Admiralty and Australian Charts in the area south of Latitude 10° round about Australia and to the west of it in Indian Ocean. The magnetic data in the Indian Ocean are based on the last cruise of the non-magnetic ship Carnegie in 1919 and are consequently very uncertain now. For any work in these oceans and for the outlying islands in India international co-operation is necessary.

For military purposes declinations on maps are required to a precision of ¼° or so. To meet this need, observations were carried out at all Repeat Stations in the year 1943-45 without observatory cover. This procedure is obviously very unsatisfactory, as the corrections for disturbances and storms which can amount to as much as 5′ have to be ignored. One remedy for this, failing permanent observatories, would be to execute observations at each station for a sufficient number of days at different hours of the day to get a good approximation to the true normal value for the place, but this would mount up the cost of the field work.

From the scientific point of view also, the case for the study of secular variation is no less strong in spite of the inherent difficulty of its determination. There is no adequate explanation yet about the genesis of secular variation. It most probably arises from changes within the crust and may well be due to slow movements of the crust with respect to subcrustal material. It is not improbable that there are slow dynamic processes in progress in the subcrustal layers and an intensive study on the shift of the isopor may help in their elucidation. From this point of view, however, the body of data available is far too small and it is imperative to plan for continuous data over long periods.

The above facts point to the imperative need of re-opening the four inactive permanent magnetic observatories in India and declaring the 80 magnetic repeat stations of India as protected areas to guard against their encroachment by structures containing iron or electric power lines.

APPENDIX 15.

NOTE ON THE IMPORTANCE OF SEISMIC AND ELECTRIC SURVEYS OF ALLUVIAL PARTS IN INDIA.

By Mr. D. N. Wadia.

Over half a million square miles of India remain a blanketted area, more or less deeply buried under surface alluvial deposits of late geological age, *e.g.* desert sands, deltas or river deposits of the Indo-Gangetic basin; or under a lava pile of comparatively older age, *e.g.* nearly 200,000 square-miles of the Bombay-Deccan. The geological composition or structure of the parts of the country so buried are completely masked and the great thickness of the cover prevents any mineral or economic investigation being carried out by ordinary geological methods in the vast extent of this blanketted terrain. The alluvial cover of the great Plains of the North, from Sind to Assam, is believed to be about 6,000 ft. thick in the central parts, though it would be much shallower along the peripheral parts; the alluvial fill of the deltas may be slightly more or less than 6,000 ft. and the lava plains of the Deccan plateau may vary from a few hundred to at least 5,000 ft. in vertical extent. The ground underlying these must contain extensions of the rocks of the *Dharwar* and *Gondwana* systems as well as rocks of *Eocene* age, the three most economically productive rock systems of Indian geology. Along the 3,000-4,000 miles border of the Indo-Gangetic Plains, where the alluvium covers the edge of the rocky country of Gujarat, Sind, Rajputana and the Punjab on the west, and the northern slopes of the Vindhyan plateau, from the Aravalies to the Hazaribagh plateau, and the Assam ranges in the east, there may occur buried ore-deposits, coal-fields or oil-fields of a workable nature. The Karnatic margin of the Deccan lavas on the southeast impinges on outcrops of the Dharwar and Gondwana formations, which, in their uncovered portions, are carriers of ores of manganese, chromite, gold and the coalfields of the upper Godavari Valley. Examination and survey of such deeply buried mineral occurrences are beyond the means of surface geological surveys. But the recently perfected technique of geo-electric, gravitational and seismic exploration of the sub-surface enables some precise data to be obtained regarding the presence of economic minerals at considerable depths below the earth surface. In the last few years, these methods have been very largely employed with success in the prospecting for oil, ores and other economic minerals. Seismic Reflection surveys have been found effective in mapping underground geological structures to depths of 15,000 ft.—a depth far greater than the depth of the Indo-Gangetic alluvium, according to all current theories. Seismic surveys have located oil-pools and favourable structures at this depth which actual boring tests have confirmed. Electric methods have successfully mapped both near-surface and deeper lying deposits and features within 4,000-5,000 ft. depth. Both these, with occasional employment of gravimetric and magnetic methods, have been largely employed in the U. S. A. and Russia for planning of an exploration programme with the help of surface geological features.

Initial exploratory studies by geophysical means should begin in India at an early date for locating of ore-deposits, coal seams, petroleum or other minerals, at first in the alluvial area (suggested above) and then in the areas of exposed rocks whose mining potentialities are yet of a doubtful nature: *e.g.* productive oil-fields in parts of Sind, Punjab and Assam, workable coal deposits underlying the lava flows of the upper Mahanadi and Godavari; the copper-bearing areas of Singhbhum and other parts of Bihar, Sikkim, Jaipur; or the lead-zinc mines tracts of Udaipur, Hazaribagh, etc. The applicability of various geophysical exploration methods to Indian conditions and to our specific problems will of course be determined by questions of relative cost, availability of personnel and instruments and the geological setting of the country.

The interpretation of geophysical data for a mining problem is a highly involved and complicated task. Such computation of data is done by men specially trained in Physics and Geology. We have at present no such trained specialists who can correlate the physical data with the geological information available from surface surveys. The training of such personnel should be the work of the Central Geophysical Institute, to be recommended by the present Committee. The Committee should, therefore, have as its first objective the establishment of such an up-to-date Central Geophysical Institute for India. It should keep abreast of the latest developments as regards modern instruments needed for prospecting by the new technique. The Institute should be competent to give advice on all matters connected with geophysics in India, besides being itself well equipped to undertake research on Indian problems.

Besides investigation of ore-deposits, oil and minerals, the following problems of interest in the general geology and structure of India need to be explored :—

(1) Proving aerial extent, height and length of the buried ridge under the alluvium of the Punjab, detected by the gravity survey. This ridge is believed to be the cause of water-logging over large parts of irrigated Punjab; and it is necessary to map this ridge in order to solve underground water problems of the Punjab and the areas to the south of it. It can be done easily by gravimetric or magnetic methods (the rocks are probably the crystalline Aravalies), supplemented by borings to assist or confirm the conclusions.

(2) The bottom profile of the Indo-Gangetic trough is likely to throw much light on the structure of India. It is necessary to make a section of the Gangetic basin by Seismic Reflection method. Magnetic survey of the southern rim of the basin might reveal the buried rock formations of the northern slopes of the Vindhyan plateau. Besides giving information *re* submerged topography and the extensions of the geological formations of the Deccan and their possible connections with the Himalayas, the section might prove of economic importance.

(3) According to Glennie, there are a number of magnetic disturbed areas in India. This was disclosed by the Magnetic survey initiated in 1910, but retrenched later before definite data could be obtained. These regions of magnetic anomalies are capable of easy and cheap determination by the Variometer survey.

(4) The all-India development survey (A. I. D.), programme recently started by the Survey of India, provides for a ten-mile network of gravity stations to measure the direction and force of gravity. This will bring forth much information of value regarding the density of the rocks both in the buried and exposed parts of India. It should be a powerful aid in surveying regions, like the Deccan Trap area, where important rock formations lie hidden under the lavas.

SURVEY OF INDIA, OFFICE OF THE DIRECTOR, WAR RESEARCH, DEHRA DUN.
D. O. No. 813/472.

Dated the 27th February 1946.

From

Dr. J. de Graaff Hunter, *C.I.E., M.A., Sc.D., F.R.S., Director, War Research.*

To

D. N. Wadia, Esq., *Mineral Adviser to the Government of India, Department of Planning and Development, Imperial Secretariat, New Delhi.*

My dear Wadia,

At the Geophysical Planning Committee in Calcutta, 4th-5th February, I did not get any more accurate idea as to the location of the desired gravity observations than that they should be at the fringe of the alluvium of the Indo-Gangetic basin. Nor do I know the priority of the work.

Could you kindly indicate on a suitable map just where the alluvial fringe occurs and how far within the g stations should be, for your purpose : and also give some idea of dates by which results should be given to be useful ?

Accessibility has an important influence on the speed of the work; and on this account stations on/at sides of motorable roads are to be preferred.

2. The AID Survey is proposed to serve as basis for all projects. While it is the target to cover (in 20 or 30 years) the whole country with a 10-mile network of AID points, the order in which this very large task is undertaken will be decided partly in relation to projects demands. The natural sequence is first to build and fix the AID marks in position and height; which also implies the determination of the deflections of the plumb line (direction of gravity): and to visit and determine g and the 3 magnetic components shortly afterwards. Some advantages are lost if this order is reversed, for the gravity stations require to be marked and heighted. The gravity field work (with Frost Gravimeter when received—it has just been ordered) is much more expeditious than the AID work: for which one detachment can hardly be expected to fix as many as 10 AID marks per month. It may accordingly be desirable to provide gravity results before the AID marks are fixed : but this will involve special height operations in most cases.

3. I should like to be clear as to the form in which results are wanted. The actual value found, reduced for height (as undoubtedly is necessary) will be available very soon after observation. If more elaborate reduction for topographical effects—with or without compensation—is needed, there will be much work to be done and delay will be considerable. I may point out that any system of reduction agreed on will need to be applied in turn to any subsequent more detailed survey of a geophysical type which is undertaken. It is accordingly in my opinion neither practicable nor useful to undertake any more system of reduction than can be represented by charts.

Bearing this in mind it seems desirable now to formulate the uses to which gravity results are to be put. Are they indeed an end in themselves or are they merely a framework for a more detailed work ?

I think you would find that a discussion with Brigadier Glennie of the points which I have raised would be useful. This should be early as Brigadier Glennie is shortly leaving for U. K. With this in mind, I am sending copy of this letter to him.

With kindest regards,
Yours sincerely,

(Sd.) Graaff Hunter.

D. O. No. 1(11)-M/46.

II

PLANNING AND DEVELOPMENT DEPARTMENT.

New Delhi, 4th March, 1946.

My dear Dr. Graaff Hunter,

Many thanks for your D. O. No. 813/470 of 27th February regarding gravity survey of parts of India. I have discussed the subject with Brigadier Glennie and I have supplied him a copy of geological map of India published in the last edition of my book—Geology of India. Brig. Glennie knows the areas which the P. & D. Department wish to have geophysically surveyed.

Brigadier Glennie agrees with me that it would be very useful to have a gravity survey made of a 10-15 mile fringe: (i) of the southern and south-eastern margin of the Deccan Traps; (ii) of the eastern margin of the rocky terrain composing the coal-fields of the Dharwar area in Bengal. These may be given priority and (iii) similar work along the northern border of the Vindhyan plateau may be taken up later. Regarding gravity stations, Brig. Glennie suggests that if we know the topographic heights within 9 or 10 ft. in the first instance, it would suffice. If particular areas need further detailed work, they may then be taken up for careful re-survey and corrections may then be applied so as to increase the accuracy of the results. This will mark out the areas which need concentrated or detailed work.

I think to begin with, a 10-mile network of gravity stations will be quite appropriate. As these gravity results are not to be used as an end in themselves but are to be a framework for more detailed work in geological prospecting, I hope the priority work will be completed within the next five years.

The rest of the Indo-Gangetic terrain in the Punjab and Central U. P. and Bengal may be taken up later and may be done on the usual 70-mile grid.

Thanking you again for your letter and with kind regards.

I remain,
Yours sincerely,

(Sd.) D. N. Wadia.

Dr. J. de Graaff Hunter, *C.I.E., M.A., Sc.D., F.R.S., Director, War Research, Survey of India, Dehra Dun.*

III

No. 1(11) M/46.

DEPARTMENT OF PLANNING AND DEVELOPMENT.

New Delhi, the 26th March, 1946.

My dear Dr. Hunter,

As promised at yesterday's meeting of the Geophysical Committee, I am sending you under separate registered cover a copy of the Geological Map of India (Plate XX of my Geology of India). I have marked in pencil the areas needing geophysical investigation. The tracts marked I, II and III should be considered as Priority areas and that marked IV to have the second priority. Of course, the different areas may be taken up by the Geodetic Survey in any order they prefer or as convenient from considerations of roads, communications, etc.

Kindly acknowledge receipt of the map. With best wishes.

I remain,
Yours sincerely,

(Sd.) D. N. Wadia.

Dr. J. de Graaff Hunter, *C.I.E., D.Sc., F.R.S., Director of War Research, Survey of India, Dehra Dun.*

APPENDIX 16.

GEOPHYSICAL PROSPECTING IN INDIA.

By Dr. G. Dessau.

It is widely acknowledged that the Survey of India and the Geological Survey of India have made important contributions to the advancement of Geophysics, especially in Geodesy and Seismology. But it is less well known that a beginning has also been made in India in the field of Applied Geophysics and Geophysical Prospecting, both by foreign and by local investigators, and that activities on a small scale have been going on during the past 20 years.

Steichen and Sierp, during the period 1911-1913, measured the radioactivity of some mineral springs of Bombay. Similar work was done by N. C. Nag in Bihar, by N. K. Chatterjee in Bihar, and on a bigger scale, all over India, during the years 1939-1941, by P. K. Ghosh of the Geological Survey of India, who measured the radioactivity of the waters of more than a hundred springs. Sir Cyril Fox of the Geological Survey of India, and with equipment supplied by this Department, had already made, at an earlier time, similar measurements in Abyssinia.

Not long after the end of the first World War, when the possibilities of Applied Geophysics were just beginning to be appreciated, the Punjab Irrigation Research Institute devised the application of the Eotvos torsion balance to the study of the slope of the hidden surface of bed-rock under alluvium, in connection with an important practical hydrological problem. The idea probably originated from the work done in Sind, in 1923, by Hungarian specialists for the Burmah Oil Co. Later, M. K. Bose after a period spent abroad, began in 1927, in collaboration with D. H. Wilsdon of the same Institute, field investigations, which were continued for three field seasons.

As remarked above, in the year 1923 the Burmah Oil Company had begun their pioneer work in the Eastern part of India with their Torsion Balance surveys, which are still going on. Whereas these surveys were made partly by personnel of the Company itself, well known geophysical firms were engaged by the same Company for electrical, seismic and gravimeter surveys at different times. According to recent reports, the Burmah Oil Co., in the period 1937-39, covered with geophysical surveys an area of 330,000 square miles (out of which 250,000 are in India proper), at an expenditure of 45 lakhs of rupees. Other geophysical surveys were made by the Attock Oil Co. in the western oil-bearing areas of India in 1931 and later.

In the meantime the few companies engaged in non-ferrous metalliferous mining in India were not unaware of the possibilities of geophysics. German specialists (of Piepmeyer-Klbof group) were engaged at considerable expense in the year 1933 to explore electrically a copper deposit in the Nellore district, and some of the leases of the Indian Copper Corporation in Singhbhum. The value of the first survey is still undecided, no mining exploration having followed it; the second was a failure; and the same, from a practical point of view has to be said about the extensive electrical survey made in 1937 by a British Geophysicist on behalf of one of the companies engaged in prospecting for gold in Mysore State.

Some of the Indian States were quite early in experimenting with geophysical methods. More than ten years ago the Mining Department of the Gwalior Government obtained an Askania-Schmidt vertical magnetic variometer, and it is understood that some practical investigations were made with it; while about three years ago the Travancore Government began the exploration of their magnetite deposits by magnetic methods. But the lead was given by the Geological Department of Mysore State, which, inspired by the survey undertaken for a private company by Broughton Edge, mentioned above, and with his help and advice, started geophysical field work during the season 1937-38. Since then their geophysicist Mr. B. Ramachandra Rao has carried out several electrical surveys with different methods on sulphide ores and graphite deposits, and has made determinations of the depth of the water-table; while it is reported that he has recently made successful determinations of the depth of bed-rock along the site of a proposed dam in the Madras Presidency.

For several years till the outbreak of the 2nd World War, Filchner made magnetic surveys in the foot-hills of Nepal and in the mountainous borderlands of India, partly for scientific purposes, but partly presumably also with practical aims.

F. W. Sharply, of the Indian School of Mines, Dhanbad, was engaged for some years in the perfecting of geophysical equipment for prospecting for mica by an A. C. electrical method; unfortunately he left the country before field tests with his apparatus could be made.

Besides the extensive radioactivity determinations of mineral waters referred to above, the Geological Survey of India had previously done occasional work in the field of Applied Geophysics. Sir Lewis Fermor, after having ascertained in his laboratory investigations the strong magnetic properties of certain Indian manganese ores, immediately envisaged the possibility of making use of these properties for prospecting. He subsequently made field measurements with a dip needle lent by the Mathematical Instruments Office, and it was confirmed that there were strong magnetic anomalies over the deposits. But on account of the unsuitability of the instrument at his disposal, these investigations could not be pursued.

At the beginning of the War, with the intensification of the search for strategic mineral deposits, interest in Geophysical Prospecting in the Geological Survey of India increased. A first piece of equipment (a "Geophysical Megger") was purchased, and repeated but unsuccessful efforts were made to get magnetic variometers from America, or from Germany through neutral channels. Equally the efforts to secure qualified personnel did not meet initially with success. Therefore the Geological Survey of India approached the Survey of India for its assistance, and a start in systematic Geophysical Prospecting was made by Gulatee of the Survey of India on problems suggested by the Geological Survey, and with the assistance of the latter from the geological side. The equipment used was partly the property of the Geological Survey (Geophysical Megger), and partly of the Survey of India (Gradiometer). During the field seasons 1941-42 and 1942-43 a study was made of the technical possibilities of prospecting electrically for mica pegmatites; and during the field season 1940-41 some gravimetric prospecting for manganese ores was carried out in the Nagpur district. Another valuable contribution of Gulatee to Applied Geophysics was his calculations of magnetic anomalies caused by bodies of known shape, calculations which have been published by the Survey of India.

Six months ago the Geological Survey of India appointed Dr. G. Dessau to work in the field of Geophysical Prospecting. He is a Mining Engineer who has specialised in the study of Mineral Deposits and who has devoted part of his activities during the past 20 years to geophysical investigations. Attempts to get more specialists are under way, and efforts are being made to get suitable equipment. Both are extremely difficult propositions in the present unsettled times. If one takes into account these difficulties, and also the time normally deemed to be necessary for getting a new initiative "going"*, it will be appreciated that a good start has been made in that already one party has been in the field for two months carrying out a "spontaneous polarization" survey on a supposed Pyrites deposit; and a second party will start in a few days' time an electric investigation on the foundations for a dam in the Damodar Valley. Both parties use or will use mainly equipment constructed at the Geological Survey. A third party, using magnetic instruments which the Survey of India has kindly agreed to give on loan, will start work within the present field season.

As regards the programme for the future, this is still in a somewhat fluid state, and the Geological Survey of India is feeling its way, and would like not to pin itself down to too specific commitments. Several big problems, such as the creation of a workshop, the increase in equipment and the collection of literature on Applied Geophysics, have been tackled and will be solved. The investigations already begun or about to be started have been chosen mainly from the point of view of the availability of equipment, and for their didactic value for the training of personnel, who, apart from Dessau, have had no previous experience in this field. It is probable that at least for a few years to come, the Geological Survey of India will not devote its main geophysical activities to the investigations at present done by the Oil Companies, which financially and technically can well look after themselves: but will concentrate on water-supply and dam foundation problems, and on the investigation of metalliferous deposits. Further, the applicability of geophysical methods to the study of some of the coal-bearing areas of India is already being investigated, although geophysics has till now generally been unsuccessful in this particular field.

In this note no account has been given of the field activities of the Geological Survey of India in investigating Earthquakes. Details of this are given in W. D. West's address to the Geology Section of the Twenty-Fourth Indian Science Congress, Hyderabad, 1937.

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APPENDIX 17.

THE GEOPHYSICAL SECTION OF THE GEOLOGICAL SURVEY OF INDIA—ITS PROGRAMME AND AIMS.

By DR. W. D. WEST.

If it is true that the need for big-scale geophysical prospecting in India was never so felt as at the present moment, it is equally true that just now there are exceptional difficulties in starting work in this field. Apart from a few types of very specialised and costly equipment, which seem available in America, years will have to pass before the full range of instruments and of general scientific supplies that are needed are likely to come on the market. Practically no trained personnel are available in India, and arrangements for training abroad are not always easy and, in any case, do not give immediate results. The needs of reconstruction in many countries of the world have apparently produced a scarcity of specialists such as practical geophysicists, and therefore it is difficult to attract highly qualified persons from abroad.

If one adds that sudden requests for urgent investigations often compel unforeseen changes in the programme drawn up, and that difficulties constantly arise in getting such instruments as are available, it will be readily appreciated that the planning of the future work of the Geophysical Section of the Geological Survey of India must remain in a somewhat fluid state, and that it would not be wise to lay down too precise a programme at this stage.

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* From Report on Discussions, on 10th January, 1936, by Heron, West, Banerji and Ramanathan: "The Seismologist and Assistant Seismologist, when appointed, will require training, and 2 or 3 years will be needed to set up the instruments in the different seismological observatories recommended by the Committee. No tangible results can, therefore, be obtained for 4 or 5 years."

The general lines to be followed, however, are fairly clear. Much of the equipment to be used during the first two or three years will be constructed locally, and will be gradually supplemented with purchases from abroad. Appointments of personnel will be made gradually, so as to keep pace with the increasing availability of instruments, and with the training of the personnel themselves. Some more specialised personnel will be recruited from abroad, or be trained abroad. Smaller and more urgent investigations will be given precedence over ambitious schemes unlikely to provide scientific or practical results for some years to come. Although the position of Applied Geophysics as ancillary to Engineering Geology and to Mineral Prospecting will not be lost sight of, arrangements for Laboratory and other fundamental investigations in subjects connected with Geophysical Prospecting will be developed gradually, in keeping with the development of the remainder of the organisation.

With this introduction, it will now be convenient to give details regarding some of the points mentioned above.

Through the courtesy of General Headquarters, India, the Geological Survey of India has been allowed during the past few months to utilise the services of an Italian Prisoner of War who has an exceptional experience in the construction and maintenance of Geophysical Equipment. He is now due for repatriation, but every effort is being made to effect his quick return and regular employment in the Geological Survey of India. Notwithstanding the present very poor workshop facilities, and the difficulty of securing raw mateirals, he has already produced, besides many odd items of smaller equipment, two potentiometers, one for " Natural Potential " investigations, the other for D. C. resistivity investigations with artificial currents, to be used mainly for the " Wenner Method ". On his return from Italy it is hoped that he will find a fairly well equipped workshop, and the number of local mistries working under him, at present two, will be increased. After concentrating for some time further on the construction of electrical equipment, so as to fully equip six field parties, he will tackle the construction of seismic equipment, as well as of other special devices for laboratory and field use.

The Geological Survey of India maintains an extensive correspondence with manufacturers of Geophysical Equipment and accessories all the world over, so as to be well informed of their availability and of the latest developments. British manufacturers have already been contacted personally by Dr. Crookshank during his recent visit to England, and it is hoped that Dr. Dessau, who is soon proceeding to Europe on leave, may be able to settle finally with them about the supply of extensive equipment.

As far as personnel is concerned, the Geological Survey of India is endeavouring to get a second experienced Geophysicist in addition to Dr. Dessau, and with this aim one senior post was advertised recently through the Federal Public Service Commission. The response has been very disappointing, but efforts for attracting a suitable scientist from overseas will continue. The junior personnel will consist of gazetted officers and of subordinate staff in about equal numbers; the gazetted officers are at present selected mainly from amongst the Assistant Geologists of the Geological Survey of India, but a young Physicist has also already been appointed, and further similar appointments may be made. All these officers are receiving training at the Geological Survey of India itself; while some of them, who are now proceeding for studies to Australia, will devote part of their time to Applied Geophysics. It is also hoped that another Assistant Geologist will soon proceed for training to the U. S. A. and others may follow later on.

This scientific staff, when in the field, has the assistance of Surveyors, at present kindly lent by the Survey of India, and of " Mistries ", some more of which will shortly be appointed from amongst demobilised soldiers.

As already emphasised, the speed with which the size of the Geophysical Section can be expanded is controlled by the speed with which staff can be trained, and by the facility to provide them with the required equipment. At present there are already about half a dozen junior officers on field work, assisted by Surveyors and Mistries. At the beginning of the next field season, *i.e.*, about one year after the foundation of the Geophysical Section, the number of officers on geophysical work will be about one dozen, together with a similar number of surveyors and specialised workmen. A further expansion is naturally contemplated.

The three or four field investigations which will be completed during the present field season were selected partly on account of the availability of the required instruments, and partly on account of their suitability for the training of Officers who are completely new to the subject. It is felt that these conditions will apply for some years to come. It is furthermore considered that the Section should at the moment concentrate more on the numerous smaller problems of dam foundations, river sand supplies in connection with sand stones, water supplies, metalliferous and coal deposits, etc., which may be quickly investigated with results useful for the immediate development of the country, rather than to devote much of its efforts to very big tectonic investigations, for oil or otherwise, which may give an answer only after many years and which will incur an enormous outlay and require a degree of training which will take some years to effect. It follows that for the moment most investigations will be made with electrical and magnetic methods, to which shallow-depth seismics and the so-called " minor methods " may be added in the near future.

It will be noted that this programme will give effect to some of the proposals made by Mr. D. N. Wadia. With regard to his other recommendations, a beginning should soon be made with the study of the bottom of the Indo-Gangetic trough (a problem which has long attracted the attention of Geophysical Science in India), although it falls in the category of long-range schemes. Such an investigation may prove useful for keeping at work officers and equipment temporarily freed from other commitments. As far as the study of the formation underlying the Deccan trap is concerned, useful as it would be, it is at present unfortunately almost beyond the scope of any known geophysical method. The matter will, however, receive careful consideration.

No geophysical field work, except perhaps simple routine investigation, has any hope of success if it is not backed by a suitable laboratory and research organisation at Headquarters, able to deal with the determination of physical constants of rocks, with development and testing of equipment, with model experiments, and with the more difficult interpretation problems. A beginning with a small laboratory will be made immediately, and it will be developed along with the other activities of the Section. It may later on be necessary to put it in charge of a Physicist of some experience.

APPENDIX 18.

SUMMARY OF THE RECENT WORK ON MINERAL SPRINGS OF INDIA BY THE GEOLOGICAL SURVEY OF INDIA

By DR. P. K. GHOSH, *Geological Survey of India.*

Although people in India have for centuries past been in the habit of using waters of mineral springs for baths and drink, very little systematic scientific work was done to study the properties of such waters in their relation to human health.

In 1939, Sir Cyril S. Fox, the then Director of the Geological Survey of India, initiated with the approval of the Government of India, a scheme for the systematic investigation of the mineral springs of India, in order to find out if springs suitable for commercial exploitation existed in India. The investigations were carried out for two years during which 120 springs in the more readily accessible areas of Bihar and Bombay and some of Bengal, Punjab, United Provinces and Central Provinces were surveyed.

In the field were studied the geological mode of occurrence, the temperature and the rate of flow of the water. Radon and other gases were determined in the field, the determination being further confirmed in the laboratory. In the laboratory the waters were further subjected to chemical and spectroscopic analysis. Samples were also specially collected for bacteriological analysis. In the analytical work help was sought from and freely given by recognised medical institutions.

Some of these waters emerge at a very high temperature, the highest temperature recorded being 87°C. The rate of flow of the chief springs is high being of the order of several thousand gallons per hour. In many cases the rate of flow and temperature are constant—facts indicative of the deep-seated origin of the springs and absence of contamination from surface sources. From the chemical point of view, some of the waters are comparable in properties to the reported European and American springs. There are others for which no comparable foreign types exist. Some of the waters are highly radio-emanative. Some are cold and some hot sulphur springs, others contain the carbonate and bicarbonate salts. Some are strongly and others mildly saline and some are remarkably low in mineral content.

Some of the waters were put under test for bottling with a view to their commerical exploitation. These waters were bottled in normal way and samples sent to people in different walks of life all of whom testified to their good qualities. Continued use has proved the waters to have at least palliative, if not curative properties.

The results of the investigation have been incorporated in a report which will be published in due course.

APPENDIX 19.

ATMOSPHERIC ELECTRICITY—BRIEF REVIEW OF WORK DONE IN INDIA

By Dr. S. K. Banerji.

Before Dr. (now Sir George) Simpson, then a Meteorologist in the India Meteorological Department, commenced his important series of observations on atmospheric electricity in Simla from 1907 onwards, which led to the " breaking-drop " theory of electricity of thunderclouds, observations of atmospheric electricity in India have been of a very sporadic character. Simpson's observations comprised taking of continuous record of potential gradient, charges of rain per cc., determination of conductivity of air, measurement of earth air current and many laboratory experiments to illustrate the process of generation of electric charge. Some observations were also made of the electricity of duststorms. After Simpson left India in 1920, there was a temporary stoppage of observations of atmospheric electricity by the India Meteorological Department. Observations of atmospheric electricity were resumed by Dr. Banerji and co-workers at Bombay from 1926 onwards. These comprised :—

(*a*) Continuous recording of potential gradient.

(*b*) Recording of charges of rain.

(*c*) Potential of gradient produced by lightning discharges.

(*d*) Counting the number of ions in the atmosphere.

(*e*) Earth air current (observations taken mainly at Poona).

(*f*) Charges on individual drops of rain.

(*g*) Laboratory experiments on process of generation of charge under various conditions.

Apparatus was also installed in the Meteorological Office at Poona for taking continuous records of potential gradient, and observations have been made of the conductivity of air and of the number of dust particles by Mr. Sil.

Some observations have also been taken by others, notably by Prof. Telang at Bangalore. A few sporadic observations have also been made on the effect of lightning discharges on conductors by Engineers.

At present observations are being taken only of the potential gradient at Bombay and Poona.

It will be clear from this account that the progress made so far in the measurement of atmospheric electricity in India has depended largely on a few individual workers.

2. *Importance of taking systematic observations of atmospheric electricity.*—There is no grander natural phenomenon than the lightning discharge. From time immemorial nature presented electricity in this form to mankind. Countless numbers have looked upon this phenomenon with awe and veneration, and a limited few have tried to understand the physical processes involved in it. We are still, however, not in a position to say that we understand them fully.

The thundercloud is not the only form in which nature presents its electricity ; there is electricity in duststorms, all cloud particles are more or less electrically charged. Observations of fine weather electricity show that there is a continuous flow of electricity from the atmosphere into the ground at the average rate of 10—16 ampere per square c.m. of the earth's surface and yet the earth maintains a negative charge. How this negative charge is maintained still remains a baffling problem.

Owing to its close relationship with weather the study of atmospheric electricity is of fundamental importance to the meteorological service.

3. *Elements to be observed.*—In a well planned observatory for measurements of atmospheric electricity there should be apparatus for taking :—

(1) Continuous records of potential gradient.

(2) Continuous records of earth air current.

(3) Records of electricity brought down by rain.

(4) Systematic observations of ions in the atmosphere.

(5) Conductivity of the atmosphere.

(6) Measurements of dust particles.

In addition, special observations of thunderclouds should be taken so as to obtain—

(*a*) distribution of charges in such clouds by sounding by means of alti-electrographs or similar instruments.

(*b*) *Structure of lightning discharges by the methods adopted by Schönland.*

Observations should also be made of—

(*c*) *The radio-activity of soil samples.*

(*d*) *Ionisation produced by spraying over sea surface.*

4. *Suggestions for observational organisations.*—The observations of atmospheric electricity require whole-time attention by specialists. Special installations have also to be set up for the purpose. Such observations should be undertaken at well-equipped and fully staffed geophysical institutes.

Past experience shows that the Bombay Observatory is a good location for measurement of atmospheric electricity, while Poona Observatory, owing to the enormous amount of dust produced by the local traffic, is an unsuitable location. The Bombay Observatory should be provided with staff and equipment for observations of atmospheric electricity in all its aspects.

If a Central Geophysical Institute be set up at Delhi or neighbourhood, and the location is such that there is not much dust in the atmosphere due to artificial causes, it should have a section studying atmospheric electricity.

For study of electricity of thunderclouds and structure of lightning discharges, Calcutta is the best location. Necessary staff and equipment for observations of atmospheric electricity should be provided at the Alipore Observatory.

If a magnetic and earth current observatory be set up near the magnetic equator (somewhere in the Tinnevelly district or neighbourhood) that observatory should also have a section for studying atmospheric electricity. This is also a good location for study of electricity of thunderclouds. Bombay, Delhi, Calcutta and Tinnevelly will provide representative positions for observations of atmospheric electricity.

It is also recommended that in the scheme for oceanography, observations of ions over the Indian seas should be included.

APPENDIX 20.

NOTE FOR THE 3RD MEETING OF THE PLANNING COMMITTEE FOR GEOPHYSICAL INSTITUTIONS IN INDIA.

[NOTE DATED 30TH AUGUST 1946 BY N. D. GULHATI, I.S.E., SECRETARY, CENTRAL BOARD OF IRRIGATION ON THE PRESENT POSITION AND PROPOSALS FOR THE COLLECTION OF BASIC HYDROLOGIC DATA IN INDIA.]

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It does not appear necessary to lay any particular emphasis before this Committee on the importance of systematic collection of basic hydrologic data to the development of a country. As pointed out by the Mississippi Valley Committee, " Land, water and people go together. The people cannot reach the highest standard of well-being unless there is the wisest use of land and water ". The development of a country is in a very large measure dependent on the extent to which the water resources of the country are utilized. For the well-being of human society it is also essential to prevent natural waters from doing harm. All this, no doubt, depends upon the accuracy of our knowledge of such factors as rainfall, river supplies, underground water supplies, etc.

2. Before an attempt is made to describe the present position with regard to hydrologic data in India, it will, perhaps, be useful to summarise the extent of the knowledge available in other countries. Far-reaching advances both in the nature of the data collected and in the extent of its collection have been made during the last six years of the war. Information regarding these advances is slowly filtering in and the position as reviewed below is what existed before the war.

In Europe the more active countries with respect to hydrology are France, Germany, Switzerland, Sweden, Italy and Russia.

France is the mother of the science of hydrology. She has a Bureau of Hydrology and Flood Warnings for each of her six large river basins. The important duty of this bureau is the investigation of flood conditions and the prediction of the crest of floods. The organisation is under a permanent commission composed of officers of the Ministries of Public Works, Interior, Agriculture and Commerce and representatives of navigation interests. In addition there is a bureau of Large Water Powers to study rivers, lakes and glaciers from hydrologic and other aspects for the utilisation of water power.

In *Germany* every important province has a Bureau of Hydrology. Their activities cover observation of ground water table, flood studies and flood warnings, measurements of temperature of water and soil, investigations regarding evaporation, observation of snow and glaciers, studies of seepage, ground water flow and springs and the measurements of bed and suspended load.

Switzerland.—The Swiss Bureau of Hydrology closely linked with the development of water-power issues separate publications for its different rivers on the subjects of :—

(*a*) drainage areas,
(*b*) river discharges and heights,
(*c*) river profiles and
(*d*) minimum discharges and minimum water power available.

Intensive river studies are conducted.

Sweden.—The Swedish Meteorologic-Hydrographic-Bureau observes water temperature, the chemical composition of water and maximum ice crust measurements. Extensive investigations are carried out on the tides in the Baltic Sea, lake level fluctuations, long range river forecastings, etc.

Italy.—The Italian Hydrographic Service includes amongst its duties flood warnings, measurement of tides and ocean currents, coastal surveys, water power statistics, permeability test of rocks, water temperature observations, ground water observations, river surveys, ground water supplies, etc.

Russia.—The Russian Hydrological Institute has ten main divisions ; Applied Mathematics, Hydrophysics, Hydrochemistry, Hydrobiology, Streamgauging, Hydrodynamics, Rivers and lakes, Limnology, Ground water and Talassology. In addition there are various auxiliary departments whose activities are co-ordinated by this Institute. Activities are mainly decentralised. Some special activities are : ice research, water power statistics, flood investigations, study of hydrology and oceanography.

U. S. A.—The activities in connection with hydrologic work in the United States of America have been described in a separate note* and include rainfall studies, snow surveying, forecasting of stream flow, collection of stream flow data, ground water studies, evaporation data and the data on the quality of surface water. Since 1937 the collection of this data has been very much intensified. For each separate drainage basin annual reports are issued on surface water supply, and records of wells, springs and ground water level but all these publications are on standard lines laid down by the National Resources Committee.

Egypt.—The extent of work done in Egypt is not exactly known but the Ministry of Public Works in Egypt issues regularly publications containing the " Measured Discharges on the Nile and its tributaries " and " Ten day mean and monthly mean and normal discharges of the river Nile "

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Iraq.—The Government of Iraq in the Irrigation Directorate has been issuing since 1930 publications containing information of the discharges observed in its various rivers together with the withdrawals by its canals.

3. The extent to which hydrologic data is being collected in India varies in her different parts. With the establishment of large irrigation works in the country, studies of river supplies, rainfall, etc. and the effect of the introduction of irrigation on the ground water levels were introduced in connection with these projects but the nature of the work varied with the effect of different factors on the operation of a particular project. There has been little attempt at uniformity of methods or co-ordination of the results obtained. Analysis of the data collected has been neglected except in so far as such analyses were called for to solve individual problems. In fact the nature and quality of the work being done in different parts of India is not known outside those areas, perhaps, not even to other departments in the same administration.

4. Before proceeding further it is desirable to state the various sub-heads under which hydrologic data may be collected :—

(1) Precipitation both rainfall and snowfall (below the snow line), its amount, distribution, intensity and frequency.

(2) Snow surveying (above the snow line).

(3) Allied meteorological data such as temperature, humidity, etc.

(4) River supplies—amount and variation.

(5) Ground Water Supplies—location, yield, depth and fluctuation.

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* Extract at the end.

(6) Quality of natural waters—both surface and subsoil—with regard to their dissolved and suspended contents.

(7) Evaporation :—

(*i*) From the free water surface ;

(*ii*) From barren ground in various stages of saturation ;

(*iii*) From trees, plants and crops including transpiration losses.

Each of these sub-heads will now be considered in some detail.

5. *Precipitation.*—A. *Existing Position.*—There are about 3,000 raingauge stations in India under various local administrations which are at present under the general supervision of the Meteorological Department. In addition there are, it is definitely known, a very large number of other stations under the control of canal and forest departments in different provinces and states, railways, municipalities, agricultural farms and other bodies who have established these stations for their own purposes.

While the Meteorological Department publishes the data collected annually from the 3,000 stations under its control, there is no one compilation of the data collected by other agencies some of whom, however, bring this data in some form or other in their annual reports. There must be some, however, who though record the data, do not publish it in any form.

An examination of the data available for some catchments has revealed that raingauge stations are not fully representative of the area in which they lie. The existing raingauge stations were established for specific purposes—from the point of view of agricultural operations to supply information necessary for regulation of canal supplies, for public health measures, small water supply projects, and other general purposes. Their distribution is, therefore, not fully representative of the area as a whole and no basic study can be made of seasonal or cyclic fluctuations of frequency of rainfall of high intensity and of other rainfall trends for any particular area. In the hilly parts of the catchment of our major rivers raingauge stations are few and far between —thus making it extremely difficult to establish a rational relation between rainfall and run off for the river basins.

This last problem is of very great importance in the proper correlation and utilisation of the country's water resources.

Very few snowgauges have been so far installed in the country. At some places observations of snowfall are made by rods measuring the depth of the snow fallen.

There are very few self-recording raingauge stations or such stations where intensity observations are regularly made.

So far there has been no attempt at an analysis of the data collected—meagre as it is.

B. *Proposals.*—The action that should be taken to make up the deficiency in our basic rainfall data was considered a few months ago in a meeting organised by the Chairman, Central Waterways, Irrigation and Navigation Commission. The recommendations made by that meeting are included in those listed below:—

(*a*) All raingauge stations existing in the country, but not at present under the supervision of the India Meteorological Department should be brought under the zone of influence of that Department, and all data obtained from them should be compiled and published with the Rainfall Data Volume of the I. Met. D. This will probably need a new section in the rainfall organisation of the I. Met. D.

(*b*) An inventory should be made of all rainfall data available with organisations other than the India Meteorological Department. Such data should be collected, compiled and published for as long a period as it is available. A special temporary branch of the I. Met. D. may be set up for the purpose.

(*c*) The number of raingauge stations should be increased so that for each catchment it should be possible to obtain data representative of the whole catchment. Rainfall observations can be treated as a problem in large scale sampling and it was decided at the meeting referred to above, to aim at an intensity and distribution of raingauge stations to give data correct within 10%. Besides the extent of the area, its orthography will determine the number of raingauge stations in it. For this purpose, it is suggested that the I. Met. D. should examine all catchments, one by one, and take action to install the additional gauges necessary in consultation with C. W. I. N. C. or the local administration concerned.

(*d*) In high altitudes snowgauges should be installed such that the total precipitation in the area is obtained correctly within 10%.

(*e*) Snow and rain should be recorded separately.

(*f*) A percentage of raingauges should be of the integrating type ; 10% should be the minimum to be aimed at for the present.

(*g*) Intensity observations should be instituted at some stations. It is recommended that 50% of the stations in (*f*) above should have instruments for intensity observations in addition.

(*h*) Time of beginning and end of storm should be recorded at all such stations where the observers are capable of doing so.

(*i*) The analysis of rainfall data with regard to intensity, frequency, etc., should be taken in hand, catchment by catchment.

6. *Snow Surveying.*—No snow surveying has so far been carried out in India. The importance of this work in connection with the forecasting of river supplies from snow fed streams has been brought out recently.

It has been proposed to invite Dr. Church to come to India next cold weather and help in the institution of snow surveys in this country in the catchments of (*i*) the Brahmaputra, (*ii*) the Tista, (*iii*) the Kosi, (*iv*) the Gondak, (*v*) the Ganges. (*vi*) the Sutlej, (*vii*) the Beas or Chenab and (*viii*) the Indus.

7. *Allied Meteorological data such as Temperature, Humidity, etc.*—Observations of temperature, etc., are carried out by the Meteorological Department at their regular observatories but their number is small. It is very desirable to intensify the observations of temperature, etc. It is proposed that 20% of all raingauge stations should also record dry and wet bulb and maximum and minimum temperatures. In hilly areas another controlling factor should be to have at least one temperature recording station at every 2,000 feet interval of height.

8. *River supplies.*—In connection with existing irrigation works, river supplies are accurately recorded at the heads of canal systems but there are many rivers on which there is no record of the supplies available at various times during the year. In the Punjab and Sind regular discharge observations are made at a number of points along the rivers. Similar observations are probably being made in Madras with respect to some of the inter-provincial rivers. Such observations in other provinces and states are believed to be few and far between. It is necessary that every river in the country is gauged at different points along its length. An investigation with regard to the actual position in different provinces and states is being made by the Central Waterways, Irrigation and Navigation Commission, with a view to the establishment of a network of discharge and gauge observation stations on all the rivers of the country.

Sind and the Punjab print their annual records of supplies available and utilised. Such data should be published for all rivers on standard lines to be laid down by the Central Waterways, Irrigation and Navigation Commission.

A system of flood Warnings exists on various rivers depending on the importance of river and the damage it is likely to do.

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9. *Ground Water Supplies.*—No estimate of the available ground water supply has been made so far, except in one or two isolated cases. There is, however, a system of recording fluctuations of the water table in many provinces. It is believed that Punjab, Sind, U.P. and Bombay have a failrly extensive and regular system of observing water depth in selected wells. Sind makes S.S.W.L. observations in the Barrage Canal area by means of pipes specially installed for the purpose. Possibly some arrangements also exist in other provinces but there is no co-ordination or uniformity in the work done. No regular analysis of the data so obtained is being made.

It is necessary to make an inventory of the work that is now being done at various places and then extend it to the whole country in a proper manner. A ground water section has recently been opened under the Agricultural Department of the Govt. of India which will be transferred shortly to the Central Waterways, Irrigation and Navigation Commission. For operational areas (Docks) this section should make a study of—

(*a*) locations where S.S. water is available for withdrawal for agricultural or other purposes,

(*b*) yield *i.e.*, the amount of water that can be withdrawn continuously without depletion of the water table,

(*c*) depth at which water is available,

(*d*) the fluctuation in the depth of the S.S.W. table—seasonal or over a long period.

10. *Quality of Natural Waters.*—Nothing has been done under this sub-head anywhere in the country whether with respect to surface runoff or with respect to subsoil waters. All surface waters are generally fit for irrigation but the quality of subsoil water varies. It is important that we should know the tracts from which subsoil water should not be drawn for irrigation to prevent deterioration of land by the application of such waters. With regard to both subsoil

waters and surface waters their dissolved mineral content should be ascertained to determine their suitability for various industrial and other uses and with regard to surface waters, it is also important to determine their suspended detritus charge. The latter has a long-range influence on the behaviour of the rivers, rise of river bed, etc.

It is suggested that the ground water section referred to in paragraph 9 should be responsible for determining the quality of subsoil waters. For analysis of surface waters the Central Waterways, Irrigation and Navigation Commission and the Irrigation departments of provinces should undertake the study.

11. *Evaporation.*—Little work has been done in the country and proposals must be framed to carry out systematic and extensive observations all over India. It has been recommended by the meeting referred to in para. 5B above, that to start with observations should be made of evaporation from free water surface at 50%, of the observatories of the Meteorological Department. (There are 400 such observatories in India.)

As regards evaporation from soil and transpiration losses, etc., it is understood that the work is being done at farm observatories (80 in number) recently established by the Agricultural Departments in conjunction with the India Meteorological Department. The nature of the work being done at these places should be ascertained together with their location and proposals for extension of the work particularly to hilly areas should be examined. This investigation may be made by the India Meteorological Department.

12. *Research and Standardisation.*—Except for a small research organisation under the Meteorological Department, there is no research carried out in our country on the improvements in and development of apparatus and methods employed in the different observations described above. In India and Ceylon there are, however, ten hydraulic research laboratories in various stages of development. The one in the Punjab may be said to be at a fairly advanced stage of development but the others need large extensions before they can be called first class research stations. At these stations the work includes development in the methods of observation of river discharges, study of detritus, and of the behaviour of rivers. The Central Board of Irrigation assists in the co-ordination of work done at these research stations.

It appears necessary that the 10 stations referred to above are fully developed and further that the research organisation under Meteorological Department be developed into a large and important organisation for carrying out research on meteorological instruments and methods.

13. *Inspection Agencies.*—The India Meteorological Department has a small organisation for periodic inspection of their observatories and of raingauge stations now under their control. The inspection at present conducted is not considered sufficient and it was recommended at the meeting previously referred to, that the inspectorate of the India Meteorological Department should be adequate enough to ensure that apart from the regular observatories, each raingauge station is inspected at least once a year by a gazetted officer or a qualified inspector of the India Meteorological Department. To obtain this and to cover the large number of existing stations now to be brought under the supervision of the India Meteorological Department and the large number of those yet to be installed, the inspectorate organisation of the India Meteorological Department will need to be enlarged very considerably.

14. *Programme of Work.*—The meeting referred to above, considered that it was desireable that the development outlined above should be effected according to a programme extending over three years.

References.

1. Physics of the Earth IX—Hydrology—Meinzer.

2. European Hydrologic Activity—Samuel Shulrtz—American Geophysical Union—19th Annual Meeting 1938.

3. Deficiencies in Basic Hydrologic Data—National Research Committee, Sept. 1936.

GEOPHYSICAL ACTIVITIES IN THE U. S. A.

[*Extract from a note referred to in para. 2.*]

In the United States many Government agencies have been established for hydrologic investigations. The following may be mentioned :—

Geological Survey	Surface and ground water hydrology.
Weather Bureau	Precipitation, etc.
Western Interstates Snow Survey conferences	Snow surveying through several agencies.

Army engineers	Stream dynamics and river systems.
Forest and Soil Conservation Service	Infiltration, erosion and transpiration.
Deptt. of Agriculture National Hydraulic Laboratory of the Bureau of Standards Bureau of Reclamation The T.V.A.	Various phases of hydrology.

In addition to the above, work is done in various universities, technical schools, etc. and co-ordination is carried out by the Water Resources Committee.

The American Geophysical Union was formed in 1919 as a part of the International Union. Its sections are :—

(*a*) Geodesy,

(*b*) Seismology,

(*c*) Meteorology,

(*d*) Terrestrial Magnetism and Electricity,

(*e*) Oceanography,

(*f*) Vulcanology,

(*g*) Hydrology,

(*h*) Tectono-physics (since April 1940).

The object of the American Union is to assist in the work of the International Union and to promote and co-ordinate various branches of Geodesy and Geophysics in U.S.A.

In 1941 there were 1,344 members paying a subscription of 3 dollars each. In addition there are a number of *ex-officio* members.

Meetings of this Association are held annually. Regional meetings are held in addition.

APPENDIX 21.

MINUTES OF THE MEETING BETWEEN CENTRAL WATERWAYS, IRRIGATION AND NAVIGATION COMMISSION AND METEOROLOGICAL DEPARTMENT OF INDIA, HELD AT DELHI ON THE 10th AUGUST 1946.

Present :—

1. RAI BAHADUR A. N. KHOSLA (*in the chair*).
2. MR. S. C. MAJUMDAR, *Member* (*W. and N.*), *C. W. I. N. C.*
3. MR. MOHSIN ALI, *Irrigation Member, C. W. I. N. C.*
4. DR. S. K. BANERJI, *Director General, Meteorological Department.*
5. MR. V. SATAKOPAN, *Assistant Meteorologist.*
6. RAI BAHADUR KANWAR SAIN, *Superintending Engineer, Punjab.*
7. MR. N. D. GULHATI, *Secretary, Central Board of Irrigation.*
8. MR. M. D. MITHAL, *C. W. I. N. C.*
9. MR. R. P. VAISISTH, *C. W. I. N. C.*
10. MR. M. L. SOOD, *C. W. I. N. C.*
11. LT.-COL. BALWANT SINGH NAG, *C. W. I. N. C.*
12. MR. M. R. RANGASWAMY, *C. W. I. N. C.*

The subject of the agenda was taken one by one and after discussion decisions were arrived at on the agenda :

Items 1 and 2—

(1) To consider and lay down a general policy for the collection of hydrological data *i.e.*, rainfall, snowfall, temperature, humidity, evaporation, wind velocity, etc. in catchments all over India.

(2) To consider the extent of facilities in respect of item (1) that exist at present and further facilities, *e.g.*, setting up of raingauge, snowfall, temperature, humidity, etc., stations which are necessary to be provided in catchments and the order of their priority.

1. It was agreed that the Inspection Directorate of the Meteorological Department of India should be strengthened to provide for a regular inspection of observatories, raingauge stations, etc.

It was agreed that all the raingauge stations should be inspected once a year by a gazetted officer or by a qualified inspector of the Meteorological Department. Based on this, the Director General of Observatories was requested to work out the new strength of this Inspection Directorate.

(*Action—Meteorological Department.*)

2. So far as the rain gauge stations are concerned the objectives are :—

(*i*) Public Health.

(*ii*) Agriculture.

(*iii*) Run-off :—

(*a*) Water resources ; (*b*) Seasonal and cyclic fluctuations and trends ; (*c*) Floods.

At present the observatories and raingauge stations have been generally planned to meet the general requirements of Meteorological Department with particular reference to agriculture, but in view of objective (*iii*) *i.e.*, run-off, the time has now come for formulating a general policy as to the intensity of these raingauge stations keeping in view the maximum permissible error for predicting individual floods of the main run-off over a certain period. With that in view the Meteorological Department will make a special study, in the course of time, of India as a whole, catchment by catchment. Special waterways maps of India are being prepared by the Survey of India Department and will be supplied to the Meteorological Department as soon as received.

(*Action—Meteorological Department and C. W. I. N. C.*)

3. It was generally agreed that 10 per cent error in the calculations of individual floods should be accepted as a general basis. The Meteorological Department will work out the required intensity of the stations on this basis.

(*Action—Meteorological Department.*)

4. It was agreed, as a matter of general policy, that the capital and recurring charges in respect of raingauge and other observation stations put up in the provinces for general purposes should be met from the provincial revenues. In case of States, they should be met from the State revenues, if possible, otherwise by the Centre. In respect of additional observatories for general purposes or otherwise, the responsibility should lie with the Central Government chargeable to the budget of the Meteorological Department, except in respect of specific projects, in which latter case, they will be chargeable to these projects. Regarding the rain gauge and other observation stations set up for the special projects, both capital and recurring charges shall, for the time being, be met from the budget allotment of the projects concerned.

The instruments and methods of observation and record should be according to the standards laid down by the Meteorological Department irrespective of the fact whether this work is done by that Department or by C. W. I. N. C. If desirable, certain instruments should be obtained by the Meteorological Department as part of their stock, or as part of the stock of the C. W. I. N. C.

(*Action—Meteorological Department and C. W. I. N. C.*)

5. The part of the organisation of the India Meteorological Department which deals with the existing instruments and invents new types of instruments should be strengthened as necessary to cover not only the work in connection with new raingauge stations, but the observatories and other recording stations envisaged in item (1) of the agenda, the necessity of which was discussed in detail.

In addition to the observation stations set up by the Meteorological Department, quite a large number of rainguage stations have been set up by the Canal Authorities, District Boards, Municipalities, Indian States, Railways, Forest Authorities and P.W.D. for their own specific purposes. Since these will supply very useful data in conjunction with that obtained from the Central Stations, it is generally felt that the Inspection Directorate of the Meteorological Department should include such stations also in the list of inspection. The Meteorological Department should collect the data about all such rainfall stations and publish them as a supplement to the All-India Rainfall Record.

(*Action—Meteorological Department.*)

6. It was agreed that Temperature Stations should be set up to the extent of at least 20 per cent of the raingauge stations and such stations should have dry and wet bulb, and maximum and minimum temperature recorded therein.

In hill areas it will be necessary to have temperature observations at every 2,000 ft. interval of height and this may increase the number of stations.

(*Action—Meteorological Department.*)

7. Half the number of regular Meteorological Observatories should also record evaporation from free water surface. Evaporation from soils is probably being observed in Farm Stations. The question of extending these Farm Stations to special projects should be considered.

For special projects the evaporation observations from soils should be conducted in hill area stations that may be set up.

(*Action—Meteorological Department.*)

8. Of the new stations to be put up, 10 per cent should be self-recording raingauge stations. The same policy should be followed throughout India according to the time schedule. Of these 10 per cent stations a certain proportion should have also barographs, thermographs, self-recording instruments of temperature, pressure, humidity, wind, etc. This proportion will be determined by the Meteorological Department from above and other general considerations.

(*Action—Meteorological Department.*)

9. Ten per cent of all our stations should have self-recording raingauges, half of which should be intensity stations.

(*Action—Meteorological Department.*)

10. There are no observatories in India for observing snow excepting the one at Leh (11,000 feet high) and it was agreed that snow observations should be sited near the snow lines in the different catchments, namely (1) Brahmaputra, (2) Tista, (3) Kosi, (4) Gandak, (5) Ganges, (6) Sutlej Valley or Kala Valley and (7) one either in Bias or Chenab and (8) in the Indus territory. Below the snow line the rain-gauge stations should allow for measuirng snow, the exact details of measurements to be determined by the Meteorological Department. The rainfall and snowfall will be recorded separately.

(*Action—Meteorological Department.*)

11. A programme for a complete set up of the above recommendations will be about three years.

(*Action—Meteorological Department.*)

Item 3.—To consider plans for the setting up of observation stations for the collection of hydrological data in specific catchments like the Kosi, Mahanadi, Sone, Chambal, etc.

The Meteorological Department will prepare plans for the setting up of observation stations for the collection of hydrological data by catchments of the Kosi, Mahanadi, Tista and Sone. and submit these to C.W.I.N.C. for approval. The plans will be reviewed by a separate committee for each catchment and the states concerned will be consulted though their representation on these committees will not be necessary.

(*Action—Meteorological Department.*)

Item 4.—To consider in respect of item (3) the qualifications and pay scales of personnel to be recruited and the directive to be issued to them for various classes of work.

The Meteorological Department will submit to C.W.I.N.C. their plans for the establishment of observation stations in the different catchments, namely Kosi, Mahanadi, Tista and Sone, and on approval by C.W.I.N.C. will proceed. Qualifications, pay scales, etc., will be the same as for the Meteorological Department and the expenses will be borne by the C.W.I.N.C., the cost being met by the respective projects or from the general budget of C.W.I.N.C.

(*Action—Meteorological Department and C.W.I.N.C.*)

Item 5.—To consider arrangements for co-ordination of activities of the C.W.I.N.C. and the Meteorological Department in respect of hydrological work.

The Meteorological Department will submit periodical report at three montly intervals after the receipt of the approval of the plans mentioned in item 3 and financial sanction. This three-monthly report will be inclusive of all the projects in hand. These reports will then be reviewed at a joint meeting of the C.W.I.N.C. and the Meteorological Department and the relevant matters discussed and decisions arrived at.

It was also resolved that C.W.I.N.C. should be represented on the Joint Meteorological Committee which is already set up in the Meteorological Department and holds monthly meetings. This committee comprises of representatives of Air Hqrs., Dg. Civil Aviation, Navy, Agricultural Department and Army. Representatives of other departments interested in particular items also participate. The Director General of Observatories will take action with the Government of India for taking a representative of C.W.I.N.C. on this committee.

(*Action—Meteorological Department.*)

Item 6.—To consider advisability of inviting Dr. Church to India, terms of emoluments and reference and the programme of visits.

It was resolved that an invitation should be extended to Dr. Church to visit India about January and in the meantime men should be recruited with sufficient scientific background who will be prepared to work on the snow line, and unless they know ski-ing already would be prepared to take lessons in it for the purpose. The scales of pay for these men will be determined by the D.G. Observatories, Meteorological Department, Government of India. A request for creating these posts will be made from the C.W.I.N.C. immediately.

Secondly the request for deputation of Dr. Church will also be made by C.W.I.N.C. on the basis of the letter read out by Rai Bahadur Kunwar Sain and other information supplied by Dr. Banerji. In this connection a resolution of the C.B.I. is recorded. It will be necessary to charter a special plane and get him to India. Dr. Banerji promised to forward a note on this subject.

(*Action—Meteorological Department and C.W.I.N.C.*)

Item 7.—To consider the setting up of seismological stations in the Kosi Valley in particular, the personnel to be employed and the equipment to be immediately ordered in this connection.

The two officers mentioned in item 9 will report on suitable site for a seismological station at Khatmandu and somewhere near the Kosi dam site and the Meteorological Department will thereafter prepare plan and estimates for setting up strong motion seismographs as well as seismograph of Wood Henderson and Milne Shaw type, and the staff required for these. Seismological stations are also required to be installed at Sambalpur dam site and Tista dam site.

The Meteorological Department will proceed to make arrangements for the necessary equipment.

(*Action—Meteorological Department and C.W.I.N.C.*)

Item 8.—To consider the question of training of staff of C.W.I.N.C., etc., for hydrological work.

The Meteorological Department will provide facilities for the training of staff of C.W.I.N.C. in its Hydrology Branch at the Meteorological School at Poona. For the observatories, staff will be recruited and trained by the Meteorological Department in the usual way.

(*Action—Meteorological Department and C.W.I.N.C.*)

Item 9.—To consider training of Nepalese personnel in Hydrological and Seismological work.

As it is apprehended that qualified Nepalese for the post of observers would not be willing to go to Poona for necessary training the D.G. of Observatories agreed to send two qualified instructors to Nepal. They will train observers and also establish a First Class Observatory, at the cost of C.W.I.N.C. If Nepalese personnel be available for higher posts like Meteorological Assistants or Professional Assistants, they will have to go to Poona for training. They should be Science Graduates or M.As.

(*Action—Meteorological Department and C.W.I.N.C.*)

APPENDIX 22.

HYDROLOGIC DATA.

Ever since its formation, the Central Board of Irrigation has had under examination various aspects of hydrologic data, and the importance of collecting them in a systematic manner. Various resolutions recommending to the Government of India and the provincial and state governments measures towards this end have been adopted in the past. At its last meeting, however, the Board passed a very comprehensive resolution on the collection of all kinds of basic hydrologic data* necessary for optimum development of the water resources of the country. This resolution is of wide interest and is published here for general information.

" Resolved that the Board is of the considered opinion that for the full and optimum development of the country's water resources, it is essential to observe and collect basic hydrologic data in as comprehensive a manner as possible, and for this purpose makes the following recommendations :—

I. METEOROLOGICAL DATA.

(*A*) *Rain gauges.*—" 1. The number of raingauge stations in all catchments should be increased, where necessary, so that for each catchment it is possible to obtain data representative of the whole catchment. In addition to the extent of the area, its orthography will also determine the number of raingauge stations required in it, and their distribution. The determination of the number of raingauge stations in a catchment and their distribution should be treated as a problem in large scale sampling. For the present, the aim should be to obtain data correct within 10 per cent.

" 2. The integrating type is recommended for inaccessible localities ; also at least 10 per cent of all raingauges in a catchment should be of this type.

" 3. In other locations the standard type of raingauge adopted by the India Meteorological Department should be used. Where facilities exist the duration of heavy rainfall should be recorded.

" 4. Intensity observations should be instituted at some stations. It is proposed that 5 per cent of all the raingauge stations should have instruments for intensity observations in addition.

(*B*) *Snow Gauges.*—" 1. In high altitudes snow gauges should be installed, such that the total precipitation in the area is obtained correctly within 10 per cent.

" 2. Snow should be recorded separately from rain.

(*C*) *Snow Surveying.*—" For catchments above the snow line snow surveys should be carried out every year. The Board recommends that the services of Dr. Church be obtained to institute snow surveying in the country.

(*D*) *Temperature and Humidity, etc.*—" At least 20 per cent of all raingauge stations should also record humidity and maximum and minimum temperatures. In hilly areas it is necessary for each catchment (or unit area adopted) to have at least one temperature recording station for every two thousand feet interval of height.

(*E*) *Agency.*—" 1. Agencies for installing and operating rain and snow gauges and instruments for recording temperature, humidity, etc., should be decided in consultation between (1) Provincial and State Governments concerned, (2) India Meteorological Department, (3) Central Waterways, Irrigation and Navigation Commission. Sub-Committees should be formed for different catchments.

" 2. The India Meteorological Department should examine all catchments one by one, and take action to have additional gauges, as necessary, installed in consultation with the Central Waterways, Irrigation and Navigation Commission, or the local administration concerned.

" 3. All raingauge stations existing in the country, but not at present under the supervision of the India Meteorological Department should be brought under the zone of influence of that Department.

" 4. All data obtained, whether from the stations now under the control of the India Meteorological Department, or from those now under the control of other administrations, and from those which will now be installed, should be compiled and published by the India Meteorological Department in annual rainfall data volumes. Evidently, it will be necessary to enlarge considerably the present rainfall organisation of the India Meteorological Department.

" 5. An inventory should be made of all rainfall data available with organizations other than the India Meteorological Department ; such data should be collected, compiled and published by the India Meteorological Department, as supplementary rainfall data volumes for as long a period as possible. A special temporary branch of the India Meteorological Department may have to be set up for the purpose.

" 6. The analysis of rainfall data for different catchments with regard to intensity, frequency, trends, etc., should be made periodically according to a definite programme and the results published. The nature of the analysis and its periodicity for data obtained from individual catchments should be determined by the sub-committees to be formed for each catchment.

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* A detailed study of the subject has been made in Punjab Engineering Congress Paper No. 282, " Hydrologic Data—Its importance and collection."

II. STREAM GAUGING.

" 1. All streams should be gauged and discharges observed by the local authorities on as extensive a scale as possible The gaugings on any stream which affects more than one province or state should be co-ordinated by the Central Waterways, Irrigation and Navigation Commission.

" 2. Automatic self-recording gauges should be installed at key points.

" 3. All data on flow of streams and rivers in the country should be published in yearly volumes and all such publications should be co-ordinated by the Central Waterways, Irrigation and Navigation Commission.

" 4. The Board is unable to recommend any specific method for calculating the maximum probable discharge of a stream. To enable it to make a definite recommendation it is suggested that provinces and states should furnish the data available with them to the Research Committee on the form appended to the 1945 resolution on this subject.

" 5. Data should be collected and analysed in co-operation with the Meteorological Department to yield :—

" (*a*) The relationship between frequency, intensity and duration of rainfall, at selected stations in India, and

(*b*) The application of the results of (*a*) to run-off discharges.

III. GROUND WATER SUPPLIES.

" 1. Investigations should be carried out to determine for specific areas (doabs)—

" (*a*) Locations where sub-soil water is available for withdrawal for agriculture or other purposes.

" (*b*) Yield, that is the amount of water that can be withdrawn continuously or at regular intervals without depletion of the water table.

" (*c*) Depth at which water is available.

" (*d*) The fluctuation in the depth of the water table—seasonal or over a long period.

" (*e*) The replenishment of the water table that occurs during normal and abnormal rainfall.

" (*f*) The economy of withdrawing supplies from the sub-soil for agricultural or other purposes.

" 2. The actual investigations should, as far as possible, be left to local administrations, but a central organization should assist in co-ordinating and standardizing the work involved, and should be prepared to take it up where local administrations do not feel interested.

" 3. A very pertinent study under this head relates to the regeneration in rivers. It appears desirable that the Central Waterways, Irrigation and Navigation Commission, in conjunction with local Irrigation Departments, undertake a comprehensive study of the supplies available in rivers from regeneration. In this connection it would be very useful to know the different reaches of a river in which it acts as a drain and in which it actually feeds the sub-soil reservoir.

IV. EVAPORATION.

" 1. Systematic and extensive observations must be undertaken all over India. To start with, observations should be made of evaporation from free water surface at 50 per cent of the regular observatories of the Meteorological Department.

" 2. As regards evaporation from soil and transpiration losses, etc., it is understood that this work is being taken up at the farm observatories (about 80 in number) recently established by the Agricultural Departments in conjunction with the India Meteorological Department. The nature of the work undertaken at these places should be ascertained, together with their location, and proposals for the extension of the work, particularly to hilly areas, should be examined. This investigation can be made appropriately by the India Meteorological Department.

V. INFILTRATION AND SUB-SOIL FLOW.

" The determination of the rates of infiltration for different kinds of soils in various parts of the country, and studies of sub-soil flow, should be undertaken by Irrigation Research Institutes, and also at the farms of the Irrigation Department.

VI. RESEARCH AND STANDARDIZATION.

" It appears necessary that the ten Irrigation Research Institutes in India and Ceylon are developed fully and further that the research organization under the Meteorological Department be extended into a large and important organization for carrying out research in Meteorological instruments and methods. There is great need for standardization in methods, in forms, and in the nature of publication of data.

VII. INSPECTION AGENCIES.

" The India Meteorological Department has a small organization for periodic inspection of their observatories and of rain gauge stations now under their control. The inspection at present conducted is not sufficient and it is necessary that the inspectorate of the India Meteorological Department should be adequate enough to ensure that apart from the regular observatories, each raingauge station is inspected at least once a year by a gazetted officer or a qualified inspector of the India Meteorological Department. To obtain this and to cover the large number of existing stations, those now to be brought under the supervision of the India Meteorological Department and the large number of those yet to be installed, the inspectorate organization of the India Meteorlogical Department will need to be enlarged very considerably.

VIII. WATER BALANCE OF CATCHMENTS.

To correlate hydrologic observations and studies recommended under different heads above, the Board considers it important that a comprehensive study of the water balance of some catchments should be carried out. Such a study will include rainfall over the catchment, runoff, rise or fall in water table, evaporation, transpiration, etc. The Board recommends that to start with the Damodar catchment be selected for the study and a sub-committee formed comprising Dewan Bahadur Ramanathan, Dr. Bose and a representative to be nominated by the Central Waterways, Irrigation and Navigation Commission to work out details. "

By another resolution the Board has laid down some tentative standards for the collection of hydraulic and other data in connection with torrents in boulder rivers and streams. This resolution is as under :—

" A. Hydraulic data for the following purposes are required in preparing reservoir projects :—

1. To determine the runoff from the catchment.
2. To find the maximum flood discharge.
3. To find the silt contents, and
4. Study the hydraulics of flow in torrents.

B. The data required are :—

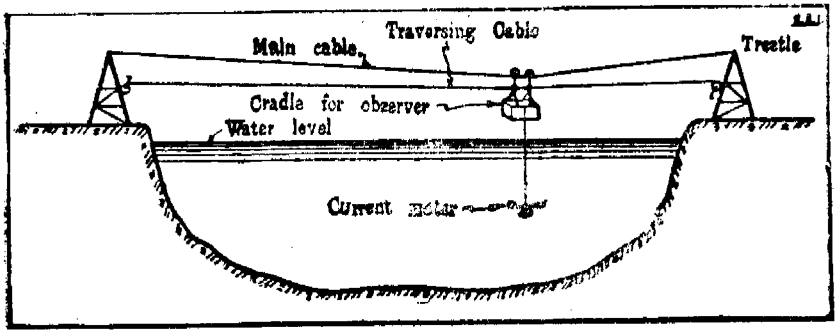
" I.—DISCHARGES—Discharge observations should preferably be taken twice a day when the river is steady.

" During floods discharge observations have to be taken more frequently. At least five observations should be taken, one when the river begins to rise, another at the peak stage, a third one when the river has fallen to the normal, with two more in between the rising and falling stages. This is with the object of determining the total volume of water flowing at each flood. If the flood lasts longer than a day, more observations for intermediate stages have to be taken.

METHOD OF DISCHARGE OBSERVATIONS.

" The ideal arrangement for taking velocity observations is by cradle gauging with current meter. Trestles are fixed on either bank of the river with a wire rope passing over them. The cradle is suspended from the wire rope, from which the current meter is lowered in the river at suitable observation points.

" The simpler method, though not so accurate would be to observe surface velocities by floats. A straight reach of 500 feet may be selected wherever such lengths are available. Cross Sections should be taken as frequently as possible. Gauges should be at the cross section site on both banks and should be read every three hours from 6 A.M. to 9 P.M. daily, when the river is more or less steady. During floods it should be read hourly all through the day and night specially at the falling and rising stages.



" It will be desirable to install automatic water level recorders wherever possible.

" Another gauge may be fixed at least 500 feet below the first gauge to record observations for determining rugosity coefficients.

" II.—Rainfall and temperature records should also be maintained.

" III.—Silt Observations—Silt observations should be taken along with the discharge observations as laid down above.

" Wherever bridges or suspension cables are available, suspended silt samples can be collected by loaded buckets, with a lid arrangement which can be closed by springs. Samples may be collected by lowering the bucket 3 to 4 feet below the surface from the bridge or suspender cable and opening the lid when the bucket is immersed. The bucket may be lowered to 0·6 depth wherever possible. The sample should be collected from the main stream. If possible two more samples from the two sides about one-sixth distant from the bank may be collected.

" Ten litres of the water collected by the buckets mixed together form one sample.

" The weight of silt in each sample so taken should then be determined.

IV. —The following additional information should also be furnished :—

1. Evaporation—daily, monthly and yearly rates of evaporation.
2. Presence of logs, or other floating matter in each flood.
3. Distance of weirs or diversion channels, if any, upstream of the gauging site.
4. General fall of the river for at least one mile above and below the gauging site.
5. Distance at which tributaries join the river above the gauging site.
6. Distance at which the torrent joins any other river below it.
7. Existence of flood banks above or below the gauging site.
8. Area of cultivation in the catchment above the gauging site.
9. Distance of the nearest bends in the river above and below the gauging site, and
10. Snow-fall in the area, if any. "

APPENDIX 23.

NOTE ON OCEANOGRAPHY.

By DR. K. R. RAMANATHAN.

Physical Oceanography and Meteorology are intimately related. The physical causes governing the circulation of the oceanic waters are essentially the same as those which govern the circulation of the atmosphere. The major currents of the atmosphere and the ocean act and react on each other. The waters of the ocean are the great storehouse for the moisture in the atmosphere. On the biological side, the study of the fauna and flora of the seas at different depths and their short-term and long-term movements and changes are of great interest to the marine biologist and from a practical point of view, to Departments of Fisheries. A study of the topography of ocean-floors, and regions of ocean currents is essential for purposes of practical navigation.

The serious study of Physical and Biological oceanography is however expensive. Special ships have to be equipped for collecting the necessary facts, the region to be covered is large and specialists have to work for many years to analyse and correlate the facts. Historically, the earliest collection of oceanographic data was made by vessels of sea-faring nations like Britain, the Netherlands and Germany, and later, expeditions with ships specially fitted for the study of deep seas were undertaken to cover regions not frequented by commercial ships. The famous 'Challenger' expedition of Sir John Murray was one of the earliest of such expeditions. Other countries like Germany, Holland, Denmark, Norway and U. S. A. have also made many oceanographic voyages with Survey Ships. At the beginning of this century, the International Council for the Exploration of the Sea was instituted with its headquarters at Copenhagen. This Institution has not only done much to study the fisheries problems of the seas of N. W. Europe but has collected much valuable data relating to Physical Oceanography and Hydrography.

Oceanography work is usually carried on by Government agencies—hydrographic departments and Bureaus of Fisheries generally—or Institutes for Oceanographic Research. Techniques of making deep-sea observations have been developed in these institutes and Government departments. Norway was a pioneer in building small sturdy vessels which could carry out intensive and extensive oceanographic work. In Europe and America there are many oceanographic Institutes now functioning. Japan had a few active Institutes and probably still has.

In India, the hydrographic work relating to Indian waters has been in the hands of the Royal Indian Marine and a considerable amount of work has been done by the Marine Survey Ship Investigator both in Physical Oceanography and Marine Biology. The British John Murray Expedition of 1933-34 organised by the British Admiralty collected valuable information regarding the topography and deep-sea oceanography of the Indian Ocean. The results of geographic and oceanographic research in Indian waters have been summarised in various papers by Mr. R. B. Seymour Sewell. The Fisheries Department of the Madras Government have a Fisheries Station at Mandapam. It is understood that the Central Government is going to start a Central Fisheries Institute at this place. The Ceylon Government has also a Fisheries Department. The Madras University had a school of Marine Biology and a Marine Acquarium but its studies were confined mainly to coastal waters round about Madras. The Provisional International Civil Aviation Organisation has recommended the establishment of an Ocean Weather Observation ship at 15°N. 65°E. Considering the importance of the subject as a fundamental science and its practical usefulness, the work that has been done in India is yet little. It is recommended that (1) Plans should be made to expand the Central Fisheries Institute at Mandapam into a well equipped Oceanographic Institute so that it will be an International Centre for oceanographic studies in the Indian Ocean. (2) Regional Institutes should also be established at Cuttack, Calcutta or Chittagong in the Bay of Bengal and at Bombay or Karachi in the Arabian Sea. (3) Each Institute should possess a small sturdy ship equipped for studying surface and deep-sea conditions, collecting deep-sea specimens and small laboratories for doing physico-chemical and biological work. (4) Suitable staff should be selected to visit and get trained in active oceanographic Institutes in Europe and U. S. A. (5) As the subject of Oceanography borders on the sciences of Meteorology, Geophysics, Hydrography and Biology, an expert sub-committee including one or two members familiar with Marine Biology should be appointed to prepare detailed plans.

सत्यमेव जयते

APPENDIX 24.

A PRELIMINARY PLAN FOR THE CENTRAL GEOPHYSICAL INSTITUTE.

Submitted by PROF. M. N. SAHA, F.R.S., AND MR. S. N. SEN.

TO

THE GEOPHYSICAL PLANNING COMMITTEE, GOVERNMENT OF INDIA.

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सत्यमेव जयते

I. INTRODUCTION.

The Government of India, Posts and Air Department, in their letter No. 18-M/10-45, dated New Delhi, the 21st January 1946, constituted a Committee consisting of the following members to consider and report on the question of organising and developing in India institutions dealing with the study of geophysics :—

1. Prof. M. N. Saha, F.R.S.
2. Dr. J. de Graaff Hunter, Sc.D. } Survey of India.
3. Brigadier E. A. Glennie. }
4. Mr. D. N. Wadia, Mineral Adviser to the Government of India.
5. Dr. W. D. West, Sc.D. (Cantab.), F.N.I. } Geological Survey of India.
6. Dr. G. Dessau. }
7. Dr. S. K. Banerji, O.B.E., D.Sc., F.N.I. } India Meteorological Department.
8. Dewan Bahadur Dr. K. R. Ramanathan, D.Sc. }

(9) Rai Bahadur A. N. Khosla of the Central Waterways, Irrigation and Navigation Commission, (10) Mr. B. L. Gulatee of the Survey of India and (11) Mr. N. D. Gulhati of the Central Board of Irrigation were later included as members of the Committee.

The object of the Committee was to consider fully the existing opportunities for geophysical work in India under the supervision of the Government Organisations such as the Meteorological Department, the Geodetic Survey of India and the Geological Survey and other state organisations and to prepare plans for future coordinated work in this important field. At the first meeting of the Planning Committee held at Calcutta on the 4th and 5th February, 1946, it was agreed that—

> " The Committee should (i) prepare a plan for geophysical work in India making full use of the existing institutions, expanding them wherever necessary, (ii) define the fields of responsibility of different departments and institutions and suggest methods of coordinating the work as a whole, (iii) prepare plans for a Central Geophysical Institute and (iv) work out the requirements as regards finance and personnel."

With regard to the Central Geophysical Institute,

> " The Committee was of opinion that India should have a Central Geophysical Institute which should work in close collaboration with the Geological Survey, Geodetic Survey and the Meteorological Department and should have a constitution similar to those of the National Physical and Chemical Laboratories. It should undertake fundamental work—
>
> (*a*) in the measurement of gravity (gravimetric work),
>
> (*b*) in seismic methods of prospecting,
>
> (*c*) in magnetic and electrical surveys.
>
> It should have an annual programme of field work which should be planned in consultation with the above departments. This Institute should also encourage teachers of physics and students from different universities to come to it and undertake research work in different branches of Geophysics."

(1). The Institute should also undertake training of geophysical problems with special reference to Indian conditions. Supply of trained personnel in any technological programme of activity constitutes the first bottleneck, and accordingly it is proposed that the Institute should offer adequate facilities for training annually a number of geophysicists commensurate with the needs of the country. (2) The Institute should also have an annual programme of field work for the education of students which should be planned in consultation with the above Government Departments. (3) It should also encourage teachers of physics and students from different universities to come to it and undertake research work in different branches of Geophysics.

Geophysics, as we shall see later, is a broad subject and includes such subjects as meteorology, seismology, terrestrial magnetism, terrestrial and atmospheric electricity, oceanography, volcanology, hydrology and geophysical prospecting. In the following preliminary plan for the Central Geophysical Institute, consideration has, however, been given to geophysical prospecting only, as a subject of teaching, research and field investigation. The complete absence of facilities for teaching and research in applied geophysics in any of the Indian universities, institutions and Government organisations and the probable demand for such specialists in the near future in an all-out drive for finding fresh mineral occurrences strongly suggest that, as a subject, geophysical prospecting should receive the first priority in the proposed Institute. This is not to suggest that the Institute should limit itself to only geophysical prospecting.

As a central institution for geophysical research, it will have in course of time, to organise research, and if need arises, training in other branches of geophysics, *e.g.*, meteorology, terrestrial magnetism, atmospheric electricity, seismology, etc., for which separate plans may be drawn up.

II. SCOPE OF GEOPHYSICS.

The science of geophysics, as the name implies, is the study of the physical properties of the earth and is as old as the science of physics itself. Geophysics is a part of what has now come to be recognised as the Earth Sciences which includes geography, geology, geodesy, geophysics and geochemistry. In the broadest sense, geophysics comprises the study of physical phenomena occurring in all parts of the Earth from all possible angles. Under geophysics, the following sciences are included :—

Meteorology ; Seismology ; Gravitation and Isostasy ; Terrestrial Magnetism ; Oceanography Volcanology ; Hydrology ; Terrestrial and Atmospheric Electricity ; and Exploration Geophysics.

Some of these divisions such as meteorology, seismology and terrestrial magnetism have been organised early and are of long standing, owing particularly to the Government interest in these sciences. The necessity of weather forecasting which has assumed greater importance with the advent of aerial navigation on a world scale has led to the establishment and expansion of the meteorological departments in all civilised countries. Seismological laboratories are now associated with the geological, meteorological, mining and engineering departments. Problems of safe navigation, tides and ocean currents and the sea as the source of food and economic materials have been responsible for the development of oceanography in which the governments of the sea-girt countries like England, Denmark, U. S. A. have come to take increasing interest during recent years. Other divisions such as hydrology and exploration geophysics are of comparatively recent development. In the subsequent discussion we shall confine our attention mainly to Exploration Geophysics.

(i) *Exploration Geophysics.*—Exploration Geophysics is the application of the science of geophysics to supplement geological exploration and as such aims at locating underground geological structures and hidden mineral deposits by measurement of physical quantities on the earth's surface. The crust of the earth as is now well known, does not consist of uniform and homogeneous composition of rocks throughout; the composition and characteristics of the crust vary from place to place, and local concentration and distribution of ore bodies and mineral deposits have taken place in an irregular manner by complicated processes of geological evolution yet imperfectly understood. This variation and want of uniformity in rock composition provide the key-stone to all geophysical exploration. "The geophysicist", as Profesor A. S. Keys writes "can only detect a discontinuity, where one region differs sufficiently from another. This is, however, a universal limitation, for man cannot perceive that which is homogeneous in nature, he can only discern that which has some variation with time or in space. Complete stagnation in time and space is to us inseparable from non-existence". As a matter of fact, geophysical methods seldom locate mineral deposits directly: they measure anomalies on the surface of the earth, which have been correlated with sub-surface geological structures favourable for concentration of certain minerals, and therefore, indirectly suggest the occurrence of mineral deposits. For instance, the pronounced minimum over a region when the results of gravity survey are plotted has been found to be associated with salt domes concealing an oil pool in the flanks. A sudden increase in the vertical or horizontal intensity in the magnetic field, known as magnetic highs, is often successful in pointing to the existence of magnetic ore bodies such as the pyrrhotite-nickel deposits in the Sudbery district of Ontario. In certain cases, correlation of anomalies in physical properties with certain types of minerals has been successful; but in many others, such measurements fail to give any indication other than of very general geological nature quite unrelated to any mineral occurrence.

The first application of geophysics to exploration practices coincided roughly with the World War I. The military urgency of detecting sub-marines, hostile aeroplanes during night and in adverse weather, and of locating enemy guns led to the development of sub-marine detectors, direction finders and sound rangers. It was argued that if hidden sub-marines, aircraft moving under cover of darkness and distant guns in enemy territories could be located accurately by physical methods, there was no reason why buried mineral deposits and underground geological features would not respond to physical methods of location.

The principal urge for the development of exploration geophysics, however, came from the disquieting prospect of an early depletion in the reserve for mineral oils. Earlier methods of finding oil by wildcatting, from oil seepages, even geological methods, including stratigraphy, paleontology, sedimentary petrology, geomorphology, etc., showed increasing signs of failure to discover new sources of oil. Geophysical methods readily appealed to enterprising oil explorers, and field applications followed, at first hesitantly in isolated instances and soon as a regular routine programme on an organised scale. During 1937-40, geophysical methods were reported to have discovered oil at the rate of 300,000 barrels for each dry hole as against the average of about 180,000 barrels during the whole life of the American petroleum industry. The much improved position of the oil industry in America to-day, due to fresh discovery of new oil beds, has been summarised by Dr. Jakosky as follows:

> "The estimated proved oil reserves in the United States are considerably in excess of those known fifteen years ago in spite of the fact that more petroleum has been produced than was previously assumed to exist. An estimated total of about 38,000 million barrels of oil have been discovered (1938) of which about 21,000 million barrels have been produced, leaving 17,000 million barrels in the ground as proved oil reserves. It is probable that many new fields will be found to augment this supply materially. Exploration geophysics has played an important part in the discoveries of the last fifteen years, and it will be only by the improvement of present methods or the development of new methods that the recent fast rate of discovery can be maintained."

(ii) *Methods of Geophysical Prospecting.*—A brief reference to some of the important methods and their fields of applicability in mineral prospecting as well as in elucidating general geological layout may be attempted. The various methods now widely employed have been, for convenience, divided into two broad classes, i.e., major geophysical methods and minor geophysical methods. The former include gravitational, magnetic, seismic and electrical methods. Under the latter, elastic properties, thermal forces, and radiations from radio-active bodies have been used for mining, engineering and military purposes. Two tables (Tables I and II), due to Prof. C. A. Heiland, of the Colorado School of Mines, are reproduced from his treatise on " Geophysical Exploration". The fields of applicability of the geophysical methods are clearly indicated.

From a careful analysis of this Table I, it would appear that the major fields are (1) oil prospecting, (2) mining for mineral deposits, and (3) engineering problems. By far the greatest and most successful application of geophysical methods has, however, taken place in oil exploration. In mining, the success of a geophysical survey is not so conspicuous, but the highly encouraging results obtained in locating placer deposits of gold, sulphide veins, bedded deposits of coal and lignite, and many others leave no doubt as to the great promise geophysical methods hold for mining practices as well. It is only very recently that the significance of geophysics in engineering problems has been properly realised. Until the advent of applied geophysics, there was no certain method of adequately grappling with engineering problems connected with dam foundation and location of water and construction materials.

(iii) *Oil Prospecting.*—All the four major geophysical methods have been employed in exploration for oil. As it has already been suggested, the purpose of geophysical prospecting is not to locate oil directly—it has not been so far possible to do so, but to study sub-soil structural features most favourable for the accumulation of oil. Depending on the nature of this buried structure, each method has its own limitations and advantages, and before an appraisal of the merits of different methods is attempted, it would be advisable to briefly refer to the geology of oil formation and accumulation. The following table (Table III) records the equitability of the various methods for different types of oil-bearing structures such as anticlines, faults, buried ridge, salt-frums, buticular and volcanic instrusions.

Electrical Well-Logging.—From a perusal of the above one would notice the striking absence of the application of electrical methods. It is true that, compared with the magnetic, the gravimetric and the seismic methods of survey, electrical methods have received far too little use in oil exploration. There is one direction, however, in which the electrical method has proved highly successful. We refer to the method of electrical well logging. This method has been developed principally by two French brothers, C. and M. Schlumberger and was first tried in the Pechelbron field in France in 1929. Later, electrical well logging method was extensively used in the U. S. S. R., U. S. A., Rumania, Venezuela and other oil producing countries.

In spite of this knowledge and great progress in exploration geophysics, application of the best method for a certain type of investigation is often limited by other factors, of which the most important are terrain conditions, cost and time. The selection of methods is often strongly determined by the terrain conditions. Until recently magnetometer, gravimeter and torsion balance could not be used in a swampy or water-logged area, although it was felt that their use would lead to highly important results. Further rugged topography, adverse surface geologic conditions, such as heterogeneous glacial beds, igneous and metamorphic rocks, seriously interfere with the work of torsion balance and magnetometers. In this respect seismic methods enjoy much greater freedom and are mostly unaffected by such adverse conditions. Considerations of secrecy and necessary permits often limit the application of seismic methods, whereas the neat and compact magnetometers and gravimeters mounted on specially designed tracks usually involve no such difficulties. Cost and time are two other important factors which play an important part in the decision of a geophysical undertaking. Geophysical exploration is always a costly undertaking, and unless the prospect of a positive result is more or less assured, prospecting companies think twice before embarking upon a geophysical programme. Considerations of competition, limited period of leases, etc., often make time an important factor.

Cost of geophysical methods.—In view of the importance of cost in geophysical prospecting, it will be of interest to consider the cost in some detail. The cost of geophysical surveys varies between wide limits, as it depends on (i) the method used, (ii) terrain and other conditions limiting speed of operation, (iii) equipment and personnel of crew, (iv) the detail with which an area is sought to be surveyed, etc.. Table IV, reproduced from Prof. Jakosky's book " Exploration Geophysics", gives some idea of the approximate cost involved in geophysical prospecting. A magnetic party thus appears to be the cheapest of all methods. This is one of the reasons of its wide application in reconnaissance survey. A seismic party is most expensive, and this expense is justified by the detailed and more specific nature of information guaranteed in this method. A gravity party is usually very quick in action, as it can cover several hundred square miles per month, whereas a seismic party cannot even tackle a few square miles in course of a month. This also introduces great difference in the final cost of survey per unit area covered.

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TABLE I.

Four Major Geophysical Methods and their Applications.

—	Methods.			Field.	Geological Application.
I. Gravitational	A. Torsion Balance			Oil	Anticlinal structures; buried ridges; Salt domes; faults; intrusions.
	B. Pendulum C. Gravimeter			....	Salt domes; buried ridges; major structural trends.
II. Magnetic	....			Oil Mining	Anticlinal structures; buried ridges; intrusion; faults; iron ore; pyrrhotite, and assoc. sulphide ores, gold placers.
III. Electrical	A. Self Potential			Mining	Sulphide ore bodies.
	B. Galvanic application of primary energy	1. Potential distribution of secondary field measured.	(*a*) Equipotential Potential profile. (*b*) Resistivity. (*c*) Pot. drop ratio.	Mining, Civil Eng., Oil	General statigraphic and structural conditions; bed rock depth on dam sites; ground water; oil structures; sulphide ore bodies; highway problems; electric logging.
		2. Electromagnetic field meas..		Mining	Sulphide ore bodies.
	C. Inductive application of primary energy			Oil, Mining	Faults; Anticlinal, etc., structure sulphide ore bodies.
IV. Seismic.	A. Refraction			Oil, Civil Eng.	Salt domes; anticlinal, etc. structures; faults, foundation and highway problems.
	B Reflection			Oil	Low dip structures; buried ridges; faults.

TABLE II.

Minor Geophysical Methods.

	Methods.	Field.	Application.
Utilising elastic properties.	Acoustic	Mining, Civil Engineering.	Mine safety; pipe leak detection.
		Military Engineering	Sapper, submarine air-plane detection; sound ranging.
		Navigation	Echo depth sounding; iceberg location.
	Dynamic vibration tests.	Structural; Civil Engineering.	Earthquake and vibration, damage tests of buildings, ground and road beds.
	Strain gauging	Mining, Civil Engineering.	Mine Safety Tests of structures.
Utilising thermal effects	Geothermal	Oil exploration	Structural correlation of wells; cementation problems.
	Thermal detection	Military Navigation	Airplane location; Iceberg location.
Gas detection	....	Oil mining; Military; Civil Engineering.	Location of oil (?); Mine safety; Poisonous gases; Gas leaks.
Radioactive measurements.	....	Mining; Oil	Radioactive ores; Well logging.

TABLE III.

Structures.	Choice of Geophysical Methods for	
	Reconnaissance.	Details.
Anticlines, Domes, etc.	Magnetic, Gravimeter, Refraction Seismic.	Reflection Seismic, Torsion Balance.
Faults	Reflection Seismic, Torsion Balance, Magnetic, Refraction Seismic.	Reflection Seismic, Torsion Balance.
Buried Ridge	Magnetic, Pendulum, Gravimeter, Reflection Seismic.	Torsion Balance, Reflection Seismic.
Salt Domes or Anticlines	Gravimeter } deep domes Torsion Balance } Refraction Seismic (domes within 5,000 feet).	Torsion Balance, Reflection Seismic.
Lenticular	....	....
Volcanic Intrusion, Dikes, etc.	Magnetic	Torsion Balance, Reflection Seismic.

TABLE IV.

Method.	Cost per month (in dollars).
Magnetic	500—700
Gravitational (Gravimeter)	3,000—5,000
Gravitational (Torsion Balance)	3,500—4,500
Electrical	3,000—5,000
Geochemical	3,000—6,000
Reflection Seismic	6,000—11,000
Refraction Seismic	6,000—15,000
Slim-hole Drilling	0·25 to 1·75 per foot of hole drilled.

Despite the cost factor, geophysical methods today constitute an integral and indispensable part in the programme of prospecting for oil by any company. It has been estimated that the oil industry in the U. S. A. spends between 15 and 20 million dollars annually for geophysical work, including research in the laboratory and field work.

(iv) *Mining for Mineral Deposits.*—The mining industry, unlike the oil industry, has made so far not much use of the geophysical methods for the location of mineral deposits. Several causes are responsible for this lack of interest. Mining exploration presents problems quite different from those involved in prospecting for oils. Unlike oil which occurs over extensive areas, most mineral bodies are deposited in small sizes of intensive local concentrations, in the form of veins, lodes, and dikes, or of placer, disseminated, and bedded deposits. The geology of rocks containing ore bodies is also far more complex than the oil bearing rocks and structure and requires closer and more thorough correlation with geophysical data. The small size of the deposits imposes depth limitation on most of the geophysical methods. Further, so far the needs of the world market have been met by ores available over the surface or within small depths of the crust but with the growing depletion of such deposits, due to increasing use of metals, efforts are sure to be directed to physical methods of locating such ores within greater depths of the crust. Seismic methods which are usually capable of revealing greater details of underground structure and have proved highly successful in oil prospecting have little application in mining exploration. The comparatively rugged terrain of mining districts is another deterrent upon geophysical methods. In view of these factors, the cost of geophysical exploration in mining is often considerably greater than that involved in oil, and for most mining companies this cost assumes prohibitive proportions.

Despite these limitations, geophysics has been applied, with increasing success, for mining purposes during recent years. The principal utility of such application, however, lies in preliminary evaluation of prospects. Favourable magnetic and electrical properties of the majority of ore bodies have made the magnetic and electrical methods an obvious choice. Theoretically, however, gravity surveys, by means of torsion balance in particular, offer reasonable possibilities, but the terrain characteristics often forbid such surveys. Seismic surveys, though less important, have sometimes been successfully used in determining thickness of over-burden and bed-rock contours. The various minerals which have so far responded to geophysical methods of exploration include gold, aluminium, manganese, nickel, chromium, mercury, tungsten, coal, lignite and many others.

(v) *Engineering Problems.*—The various engineering problems connected with the location of water tables, selection of dam-sites, the determination of foundation conditions in highway and rail road construction, detection of corrosion and leakage in gas and water and many others far too numerous to mention offer the third major field of application of the geophysical methods. It is also a promising field, but geophysics has scarcely entered this field. A fair amount of geophysical work has been carried out on foundation problems and on the location of water. It is needless to emphasize the importance of detailed information about the nature and depth of bed-rocks at a place where the construction of adam, an aqueduct , a bridge, or a tunnel is projected. In the past, failures of such constructions and fatal accidents arising therefrom were frequently due to the selection of faulty sites which could not be ascertained except by geophysical sounding. Foundation problems can now be very conveniently attacked by geophysical methods, particularly by the seismic refraction and electrical resistivity and potential-drop-ratio methods. Valuable information on the type of rock encountered in dam, tunnel or similar sites can be obtained by these methods. In connection with the Damodar Valley Scheme, geophysical work on foundation problems at the proposed dam-sites is now reported to be in progress.

Location of water is another fruitful field of application of geophysical methods. But this undertaking constitutes perhaps the most difficult task for a geophysicist inasmuch as it involves a thorough and expert knowledge of geology as well. Water occurring in the form of saline or radio-active springs permits of direct location by electrical or radio-active methods. Water in presence of salt mines, limestones or dolomites gives rise to a saline solution which can be detected by resistive, inductive or radio methods. Synclines, troughs or similar underground structural depressions are often associated with water. Geophysical methods are quite successful in locating these structures. Thus torsion balance has been applied to water-bearing gravel channels, magnetometer to igneous and metamorphic rocks containing water, and seismic and gravitational methods for locating lateral faults which may favour the local accumulation of water.

III. GEOPHYSICS IN FOREIGN COUNTRIES.

(i). *Geophysics in the U. S. A.*—Geophysical prospecting methods in the U. S. A. have been very largely developed by big mining corporations and oil companies like the Standard Oil Company, the Gulf Research and Development Company interested in the commercial value of the earth's deposits. These companies generally keep the knowledge to themselves; but during the present war some of the methods developed by them had to be placed at the disposal of the Army and the Navy for determining general subterranean conditions for location of strategic materials, enemy mines, etc. It is fairly certain that after the war the commercial mining organisation will again assume supremacy in matter of geophysical prospecting. In the U. S. A. public opinion is at present very critical about the activities of these concerns, and it is widely suggested that the Government should organise and undertake geophysical prospecting for conservation and proper use of minerals on a national basis and exert greater control on the private corporations.

In the U. S. A. work in geophysical work is at present carried out by:—

Federal Agencies,

Geophysical Laboratories attached to the Universities and Technological Institutes,

Private Research Institutions,

Research Laboratories of Private Commercial Organisations,

Geophysical Societies.

Federal Agencies.—The Federal Agencies responsible for geophysical work include the Geological Survey, the Bureau of Mines, Weather Bureau, the U. S. Coast and Geodetic Survey of the Department of Commerce, the Army Engineers and the Soil Conservation Service.

Geophysical Laboratories attached to Universities and Technological Institutes.—Several Universities encourage the study of and research in geophysics. Mention may be made of the Universities of Washington at Seattle, Minnesota and St. Louis. The Institute of Geophysical Technology of the St. Louis University has been recently (1944) organised under Dr. James B. Macelwane and is reported to be a very well equipped institute. The Institute has curriculum in:—

1. Petroleum Geophysics,
2. Mining Geophysics,
3. Seismological Engineering,
4. Geological Engineering,
5. Professional Meteorology,
6. Applied Electronics,
7. Communication Engineering.

The Massachusetts Institute of Technology has a Geophysical Section. A similar section has also been provided in the California Institute of Technology, under Dr. Gutenberg who has specialised in seismology.

Private Research Institutions.—A number of well-equipped private institutions are carrying on excellent work in geophysics. The Department of Terrestrial Magnetism of the Carnegie

Institution of Washington which carries on extensive work on Geomagnetism and on the Ionosphere is a notable example. The Colorado School of Mines at Denver maintains a Department of Geophysics under Dr. C. A. Heiland who is a distinguished authority on geophysics and has written a well known treatise on Geophysical Prospecting. This is a splendid institution for training geophysical engineers and technologists. The Woods Hole Oceanographic Institute at La Jolla, Southern California, and the Scripps Institute of Oceanography are the two important institutes for study and research in oceanographic problems. Oceanography has recently made much progress in the U. S. A., and we understand that an attempt is being made to include courses in oceanography in the educational institutions, particularly those situated near the sea boards.

Research Laboratories and Private Commercial Organisations.—Probably none of the geophysical laboratories of the Universities and research institutes, private or official, can compare, in importance or in comprehensiveness and extent of its activity, with the research laboratories of private commercial organisations. Most of the oil companies and some radio companies maintain special sections on geophysics in their research laboratories. The Indian Scientific Mission visited the laboratory of the Gulf Research and Development Company at Pittsburg. The Director Paul D. Foote was for long a well known worker in atomic physics in the Bureau of Standards and has gathered round him a batch of noted workers such as Dr. Eckhard, Dr. Nettleton (author of Geophysical Prospecting for Oil) and Dr. Muskat, the hydrodynamist (flow of liquids through sands). The annual budget of this laboratory of research and exploration is nearly 5 million dollars or about 1·7 crores of rupees.

The Gulf Research and Development Company had recently discovered with the aid of geophysical methods an extensive oil field in Saudi Arabia, which is said to contain more oil than the two American continents. The area has been found to be so rich in oil deposit that every acre can have a well capable of producing 10,000 barrels a day for 80 years. Plans for building a long pipe line to link this field with the Mediterranean on the one hand and the Persian Gulf on the other are said to have been completed.

Geophysical Societies.—The recent growth of a number of specialist societies for the promotion of geophysical studies is a clear indication of the great importance this branch of science has attained in the U. S. A. The American Geophysical Union H. Q., established in 1919, with about 1,900 members, is perhaps the principal organisation. Sponsored by the National Academy of Sciences through the National Research Council, the Union acts as a clearing house for new thoughts and ideas relating to geophysics. The executive committee of the Union is the committee on geophysics of the Council and is the American Committee of the International Union of Geodesy and Geophysics. The functions of the Union are ' to promote the study of problems concerned with the figure and physics of the earth, initiate and co-ordinate researches which depend on international and national co-operation, and to provide for their scientific discussion and publication'.

The Society of Exploration Geophysics (Post Box 6005 Houston, Texas) came into existence in 1930 and has now become an active society with nearly 1200 members. It publishes a quarterly journal, *Geophysics*, originally the *Journal of the Society of Petroleum Geophysicists.* The Society holds annual meetings at leading cities.

The American Institute of Mining and Metallurgical Engineers (29 West 39th Street, New York 18, N. Y.) has a geophysical section and publishes a journal on geophysics.

(ii) *Geophysics in Great Britain.*—The application of geophysics to prospecting for minerals has not received much attention in England owing largely to the smallness of the area. Recently, however, some oil companies are reported to have started geophysical prospecting with varying degrees of success. The D'Arcy Exploration Company (subsidiary of the Anglo-Iranian Oil Company Ltd.), for instance, has succeeded in striking a number of new sources of oil in Great Britain, of which a short account appeared in Nature, May 12, 1945. The Company has been in active operation for nearly ten years and has proved five oil fields and two areas of natural gas; the 243 wells sunk in these areas produced a total of 337,000 tons of mineral oils up to the end of 1944. The crude oil, with specific gravity ranging from 0·83 to 0·89, is reported to be of good quality, yielding good light and lubricating fractions.

Oil fields have been discovered in the neighbourhood of Newark, Duke's Wood, Caunton and Kelham Hills, Formby, Nottinghamshire and other places. Besides, the existence of a number of gas-fields has been proved at Airlaby in Eskdale, North Yorkshire, and at Cousland near Dalkeith, Scotland. The Nottinghamshire oil fields were discovered as a result of intensive geophysical work carried by the staff of the Anglo-Iranian Oil Company. Of the various geophysical methods applied, seismic refraction surveys, gravity and magnetometer methods have yielded highly useful results. The presence of a number of structural height in extensive areas in eastern Nottinghamshire and in Lincolnshire has been proved by these investigations and verified, in some cases, by actual drilling.

Furthermore, these investigations have resulted in the collection of new and important geological information on the stratigraphy and structure of the carboniferous rocks below the Permian unconformity. In addition to mineral oils, these surveys based on geophysical methods have led to the discovery of coal seams of significant thickness at Spital, Dunston, and Stixwould, of potash salts of Permian age in Eksdale, North Yorkshire, and also sylvite and polypalite deposits.

ONLY SOME TEN YEARS AGO, THE GEOLOGISTS OF GREAT BRITAIN GENERALLY BELIEVED IN THE IMPOSSIBILITY OF ANTICIPATING OIL POOLS OF COMMERCIAL MAGNITUDE IN ANY KNOWN PART OF THE UNITED KINGDOM. THIS CONCLUSION WAS ARRIVED AT AFTER CAREFUL AND INTENSIVE SEARCH FOR OIL OVER EVERY INCH OF LAND BY TRADITIONAL GEOLOGICAL METHODS, AND EXPLORATION FOR OIL WAS REGARDED AS HOPELESS TASK. THE RESULTS OF EXPLORATION FOR OIL BY THE D'ARCY EXPLORATION COMPANY, EMPLOYING GEOPHYSICAL METHODS, HAVE SHOWN THAT MERE SURFACE INVESTIGATIONS MAY BE WHOLLY MISLEADING.

Some members of the Indian Science Delegation to the Empire Science Delegation including **Prof. D. N. Wadia** and **Prof. M. N. Saha**, were enabled through the courtesy of the Burmah Oil Company to pay visits to the Gravity Observation Stations at Cirencester, in the Cotswolds, Oxfordshire. We saw a Frost Gravimeter carried in an observatory on van in working, noting small gravity differences, arising from composition, structural disposition and folding of rocks at different depths. It could take 8-10 readings of gravity from different stations, situated around a central check station, in a few hours. The observations and computations were rapid, taking only a few minutes. The merits of the Frost Gravimeter are its compact size, simple construction, portability and ease of lowering and grounding the instrument from the van on to the road surface. The recording of gravity obtained at each selected observation point has to be checked with that at the original station. The reading at each station has first to be corrected for relative height differences, even if these amount to a few feet, apart from topographical relief, so that accurate determination of height, correct up to one foot, forms a problem as important as the determination of value of gravity correct up to a milligal. When all topographic and relative altitude corrections are applied, readings of the Frost Gravimeter can be accurate to 1/10 of a milligal (for most purposes, the readings required are only up to 1 milligal accuracy). These minor relative height differences need not be taken into account when only milligal readings are required. Dr. P. Evans kindly explained to us the basic geological data to which the gravity values form a supplement.

Demonstration of a captured German Gravimeter at the Offices of the Anglo-Indian Oil Company.—This instrument was shown to us by Prof. A. O. Rankine, obviously of much more elaborate and complicated construction, provided with various devices for checking interference from outside factors; but it does not claim any greater efficiency or accuracy. Its principle was similar to the Frost Gravimeter and its portability was as easy. The Germans were said to have used it on a very large scale for the gravity survey of Germany, which and other investigations led, during the war, to the discovery of several oil fields in Western Germany, bordering Holland, producing nearly a million tons.

Visit to the Eakring oil field—20 miles from Newark, Nottinghamshire.—This is the most productive of the four new oil-fields recently brought into production in England. Their discovery was based solely on exploration of underground structures by gravity determination and their mapping by seismic reflection and refraction methods.

The productive oil horizon lies just below the Upper Carboniferous coal measures, overlying the Carboniferous limestone beds and Millstone grit. The actual reservoir-rock is a thin group of millstone grit beds. It is over 2,000 ft. in depth below the surface composed of horizonta Triassic strata. Though the beds of Millstone grit form the reservoir-rocks from which all the Eakring oil is obtained, there is some doubt as to the actual source of the oil—whether it has not come by migration from some older Palaeozoic strata below. The structure, as revealed by seismic refraction mapping, is that of a low flat anticline, in the crest of which there are saturated pockets of Millstone grit (here a rather coarse and porous sandstone of variable thickness). There is but little of gas associated with the petroleum in this field and hence there are no 'gushers' but all the oil has to be pumped. The petroleum is of good quality, rich in the lighter fractions. There are over 200 wells drilled on the Eakring anticline which produce, in the aggregate, about 100 tons of oil per day. The capacity of this field, however, has passed its peak and is slowly on the decline. It has produced over 300,000 tons of oil during war years. Further drilling is in progress to test deeper horizons.

Though indications of the presence of petroleum was well known in this and adjoining areas in Nottinghamshire (in small springs and seapages of oil, associated with the coal measures and surface rocks), the geological structure of the area, hidden under the Upper-carboniferous-Permian unconformity was not considered favourable and no serious oil prospecting was done. Geophysical methods revealed the unconformity and the structure contours of the favourable anticline underlying it and the flat and featureless Triassic rocks of the area. The Eakring field is thus entirely the result of geophysical prospecting carried out by the Anglo-Iranian Oil Company under the direction of G. M. Lees.

Seismic refraction survey of the Formby oil-field, Liverpool.—Prof. Rankin of the Anglo-Iranian Oil Company conducted a visit to this interesting field where some 8 tons of seapage oil a week flows out from pools in the surface, but whose source-rocks, or their structure, are hitherto not located. The rocks here are Upper-Triassic marls and sandstones, overlying Carboniferous beds, covered at the surface under the peaty aluvium of the Mersey. A blast charge of 480 lbs. of dynamite was exploded in a 6″ bore-hole, specially drilled to a depth of 120 ft. The ground waves following the explosion were detected by six geophones, planted equidistantly along radii, 6 miles away from the charge. These were connected independently to a recording Obervation Van equipped with suitable apparatus. More or less clear seismographic recordings were obtained from each of the six detectors, which were developed automatically in the Van and were ready for inspection in a few minutes.

The refracted seismic waves, travelling back from an underground rock-surface, differing in composition, density and structure from the surrounding surface-rocks, would give some indication regarding its depth, contours and structural disposition. The interpretation of such seismographic records, however, is a matter which needs extreme care and accuracy.

The eliminations of accidental ground vibrations at the series of geophones, at the time of exploding the charge, miles away from them, entails an elaborate system of radio-signalling and telephoning between them, the Observation Van and the station Van exploding the charge.

(iii). *Possible Geophysical Researches in Southern Africa.*—(A) *Seismology.*—Four vertical Benioff seismometers have been ordered, to be sited at Pretoria, Pietermaritzburg, Bloemfontein, Grahamstown,

1. to contribute to the International network,
2. to locate local earthquakes and contribute to crustal structure studies,
3. to study period, time of arrival relations of the Rayleigh waves for African, Indian Ocean and Atlantic paths.

Even including these instruments, it is considered that Africa as a whole has an inadequate number of seismograph stations.

(B) *Earth tremors* (due to mining) occur in a small region about Johannesburg, the magnitude occasionally approaches that of minor earthquakes. These are regarded as a valuable source of shocks for the investigation of local crustal structure. The following researches are contemplated :—

(1) "Reflection technique" to observe deep reflections at small angles of incidence on a group of centrally recording seismometers with small spacing, in order to identity reflections by their high apparent velocity. The recording mechanism will be 'triggered' by the initial waves of the tremor.

(2) "Refraction technique" to obtain travel-time curves for South Africa up to 600 miles from the focus. A Radio trigger technique may be used to start the recording, operating from the network (3) below, which will also locate focus and time of origion. A group of spaced instruments, recording centrally at high speed, is contemplated for the field station(s), again to facilitate the identification of phases by comparison of apparent velocities.

(3) A local network of stations is planned, each to transmit the oscilliations to a central recording station by radio. The records will be momentarily preserved by recording on magnetic tape so as to allow the high speed, intermittently recording equipment to come into action.

Considerable scope for valuable electronic techniques is available. Accurate location, and study of rock movements and velocity discontinuities are planned.

(C) *The use of spaced but centrally-recording seismometers* is contemplated for recording teleseisms.

(D) *Lightning and Thunderstorm Research.*—(1) Photography, and correlated oscillography, of lightning flashes. Wave forms of atmospherics. Location of thunderstorms by C. R. D. F. over the whole of Southern Africa might be done with stations in Rhodesia and South Africa only.

(2) Theoretical and experimental study of electric effects in thunderclouds. Use of radiosondes for determining the potential gradient in clouds.

(3) Meteorological relations of thunderstorms.

(4) Observation of thunderclouds by Radar equipment.

(E) *Gravity.*—Considerable gravimetric prospecting work has been done in the Southern Transvaal and Northern Free State but no linking up to absolute values has been possible. Very few absolute determinations have been made and nothing in the way of a large scale area survey has been carried out. The aim of gravimetric work in the Union will be for survey purposes and to resolve both local and continental crustal structure problems.

(1) It is hoped to prepare a detailed gravity map of the Union (by co-operation of the Universities and Trignometrical Survey). A limited number of pendulum observations would be made to control a much more complete network of gravimeter stations. This work could be extended to the whole of Southern Africa.

(2) On account of the cost of gravimeters, consideration has been given to attempt to manufacture them. It is felt that, if instruments could be more cheaply obtained, they would be more extensively used for scientific purposes.

(F) *Ages of Rocks.*—Considerable difficulty still exists in the geological correlation of South African rocks. If an organisation and technique could be developed to put an age-label on rock samples, it would be of great assistance to the geologist. The mapping of variations in surface radioactivity might also be valuable.

(G) *Earth Heat Problems.*—Part of the interest in this subject arises from the problems of ultra-deep mining which is planned on the Witwatersrand. For the rest the problem is tied up with the radioactivity and structure of deep seated rocks.

Unusually good facilities exist, in the way of numerous deep boreholes, for temperature gradient and other determinations, at depth.

(H) *Magnetism.*—Apart from cartographical requirements, magnetic investigations are largely associated with magnetic prospecting methods, which have been extensively used in the mining regions.

A problem of the reversed magnetisation of rocks requires investigation.

Interest has been evidently in the possibility of using M. A. D. type equipment for rapid magnetic surveys.

(iv) *Geophysics in Canada.*—The geophysical prospecting methods also form a course of regular instruction and research in the Canadian Universities of Toronto and the McGill University, Montreal. Ordinary methods of geological investigations are of no avail for the major areas of Canada which are covered with perpetual snow withholding from view all surface indications. Ordinary surface geological prospecting has therefore to be replaced by Geophysical methods. Over 30 years ago, Dr. Gilchrist of the University of Toronto developed magnetic exploration method which was particularly suitable for the location of bodies of iron and other magnetic ores. Quite recently a rich iron ore deposit was discovered by the use of this method in snowbound Labrador.

The McGill University has particularly developed the electrical method of prospecting. Study in this direction was first started by Prof. A. S. Eve, successor of Lord Rutherford, whose book on "Applied Geophysics" is well known.

IV. GEOPHYSICAL PROSPECTING IN INDIA.

There is a great scope for the application of geophysical methods to the exploration for oil and minerals in India. Such an application has been made, to a very limited extent, by foreign oil and mining companies and by local bodies, and activities in this direction, on a small scale, are still in progress. For instance, the Burmah Oil Company has engaged at different times well known foreign geological firms which have carried out electrical, seismic and gravity surveys. Geophysical prospecting, in a similar way, has also been conducted by the Attock Oil Company. It is known that hundreds of thousands of square miles have been surveyed geophysically at an expenditure of several lakhs of rupees.

As early as 1923, on behalf of the Burmah Oil Company Limited, Dr. Pekar and Mr. Renner of the Eotvos Institute of Budapest carried out a torsion balance survey at an alluvial area and confirmed the presence of an anticline. This is reported to be the first torsion balance survey in India, and similar surveys were undertaken in 1925, and later, more systematically, in different areas. An electrical resistivity survey carried out at Digboi in 1936 successfully located part of an anticline buried under recent alluvial deposits. In 1938, a seismic survey was undertaken in

Assam, but no success was reported. The electrical well-logging method has been employed in the oil-fields of India and Burma for many years and it has almost become a standard practice.

Before the war, the Burmah Oil Company planned ' to make a thorough and complete geophysical survey of all parts of India and Burma in which there might be any hope of finding oil, but which could not, because of the recent alluvial deposits, be successfully explored by classical geophysical methods '. The company was able to enlist the services of many able geophysicists in the employment of such well known companies as the Shell Group and the Anglo-Iranian Oil Company and had also the co-operation of the well known Petty Geophysical Engineering Company of America. The organisation, under the immediate direction of Mr. D. R. Brown, consisted of seventeen parties made up of 81 qualified men. Torsion balances were first used, and gravimeter surveys, using Holweck, Ising and Thyssen types, were undertaken soon after. The Petty Company was entrusted with the work of seismic survey. The work of the organisation proceeded well, but it was cut short by the outbreak of the war. The Government of India wanted the oil companies to concentrate on intensive production of oil from the known fields and ruled that no prospecting work should be carried out unless there was a good chance of oil being proved and refined products made available within three years.

The prospecting party was in operation for a little over two years. ' Geophysical observations were made at more than 22,000 stations, rather more than two-thirds of these being in India, and the remainder in Burma. The total area surveyed, partly in reconnaissance and partly in detail, amounted to about 330,000 square miles, of which about a quarter of a million square miles were in India ; the total cost was 45 lakhs of rupees. '

Some of the progressive Indian States such as Mysore, Travancore and Gwalior also claim to have applied geophysical methods for purposes of survey and mineral exploration. The Geological Department of Mysore has carried out several electrical surveys on sulphide ores and graphite deposits and has determined the depths of water-table in a number of instances. The Governments of Travancore and Gwalior are said to be using magnetic methods in their explorations for magnetic ore bodies.

Recently the Survey of India and the Geological Survey have shown certain amount of interest in geophysical methods of prospecting. Mr. B. L. Gulatee of the Survey of India, under request from the Geological Survey carried out geophysical prospecting for hidden deposits of manganese ores in the alluvial area of Parsoda in the Central Provinces. The deposits of manganese ores buried completely under thick deposit of alluvium, were located by gravity methods. The Geological Survey of India has recently employed Dr. Dessau an Italian Geophysicist and is at present deeply interested in the application of geophysical methods to the problems connected with water supply and testing of dam foundation rocks which may lie buried under a thick cover of alluvia.

The geophysical work so far carried out in India has been scrappy and unsystematic, and proper organisation needed for such work is mostly non-existent, or utterly inadequate. The vastness and immensity of the scope of geophysical prospecting in this country is reflected in the fact that over half a million square miles lie buried under surface alluvial deposits of late geological age. The depth of the alluvial cover in the vast stretch of land from Sind to Assam is estimated at about 6,000 ft. under which lie buried the three most economically productive rock systems of Indian geology, *viz.*, those of Dharwar and Gondwana systems as also of the Eocene age.

Examination and survey of such deeply seated mineral deposits are beyond the scope of surface geological surveys ; geophysical methods, such as magnetic, gravimetric, seismic and electrical, can alone provide reliable techniques for exploration of minerals at such great depths.

V. THE CENTRAL GEOPHYSICAL INSTITUTE.

The proposed Central Geophysical Institute, as we have already stated, should (*a*) train annually a number of applied geophysicists, (*b*) undertake geophysical research, and (*c*) organise regular field parties for prospecting work.

(i) *TRAINING OF GEOPHYSICISTS.*—Applied geophysics is a super-structure built on the foundation of physics, geology and mathematics. At present hardly any Indian University or teaching institution turns out graduates simultaneously equipped with fundamental knowledge in all these three sciences, *e.g.*, physics, geology and mathematics. Colleges offer graduate courses in physics, mathematics and chemistry, but few in geology. Accordingly, it is suggested that students seeking admission in the Geophysical Institute must have graduated in at least any two of these subjects, *e.g.*, physics, geology and mathematics.

The curriculum in these subjects, as followed in most of the Universities, lays undue emphasis on the pure or the theoretical aspect of the subject. This makes it difficult to offer courses in geophysics directly to the graduates of the Indian Universities. Such students should be required to go through a pre-requisite course in physics, mathematics and geology in which emphasis will be laid on such topics as have direct bearing on applied geophysics.

It is proposed to offer a three-years' graduate course and one year's post-graduate course in geophysics. Students who have graduated in physics, geology and mathematics may be admitted to the Second Year class. It is intended to train two types of graduates (*a*) Petroleum Geophysicists and (*b*) Mining and Engineering Geophysicists. The students who will successfully complete the post-graduate course as well, will be recognised as Geophysical Technologists.

The Graduate Course.—Courses in geology, mathematics, physics and geophysics and their distribution over the three years have been fully indicated in Table V. Pre-requisite courses in geology, physics and mathematics will be offered during the first and the second year. Courses in geophysics proper will be introduced at the beginning of the second year and will be imparted simultaneously with the pre-requisite courses continued from the first year. In the second year, the courses in geophysics to be taken up will include (*a*) introduction to geophysical methods and (*b*) magnetic prospecting.

Applied geophysics has been utilised mainly for oil exploration and for finding new mineral resources and solving engineering problems of varied descriptions. Accordingly, it is desirable that the graduates in geophysics should specialise either as petroleum gephysicists or as mining and engineering geophysicists. At the beginning of the third year, the students should enrol themselves for courses either for petroleum geophysics or for mining and engineering geophysics. Those who have taken the former should go through a course in economic geology, petroleum geology and sedimentary petrology and will be required to take up gravitational methods of prospecting, well-logging, and seismic and acoustic methods of prospecting. Those intending to specialise as mining and engineering geophysicists will be required to go through a course in economic geology, ore deposits, electrical prospecting and seismic and acoustic methods of prospecting.

Post-graduate course.—It is recommended that the Institute should provide for one years post-graduate course to the graduates of the Institute, to enable them to qualify as *Geophysical Technologists.* The course of study should include (*a*) Radio-active prospecting, (*b*) geothermal methods of investigations, and (*c*) one of (1) gravitational methods of prospecting and (2) electrical prospecting, not previously taken. In addition to these, each student will be required to undertake a piece of research work in any of the major geophysical methods and submit a thesis paper.

(ii) *RESEARCH AND FIELD INVESTIGATIONS.*—The Institute should maintain a programme of research and field investigations. It is not possible to lay down in the preliminary report the various problems on which geophysical research should be conducted. Such programmes can be prepared by geophysical experts after the Institute has come into existence. It may, however, be stated that development of instruments and techniques and determination of physical properties of Indian rocks of geophysical importance may form immediate subjects of investigations.

Organisation of field parties should take place in collaboration with the Geological Survey, the Geodetic Survey and such other interested Government organisations. The field parties will be formed out of the research staff and senior students of the Institute. The Institute should also cooperate with petroleum, mining and engineering industries and make available such expert advice as they will be in need of in matters of geophysical exploration.

Details of courses, laboratory equipment, staff, etc., are worked out in what follows.

(iii) *COURSES.—An outline of graduate and post-graduate courses in geophysics with details of pre-requisite courses in geology, mathematics and physics.—*

(*a*) GEOLOGY.

First Year.

Physical Geology.—Study of materials of the lithosphere, the surface features of the earth and their origin ; primary and secondary rock structures ; volcanism, earthquakes ; metamorphism ; mountains ; the origin, types and distribution of mineral deposits ; fundamental laws and principles of historical geology.

Laboratory work with topographic maps.

Field Trips.

TABLE V.

Graduate Course.

Qualifying as (a) Petroleum Geophysicist and (b) Mining and Engineering Geophysicist.

Post-Graduate Course:

Geophysical Technologist.

—	I Year	II Year.	III Year.	IV Year.
Geology . . .	Physical Geology ; Mineralogy ; Petrology ; Historical Geology ; or Stratigraphy.	Stratigraphy (special reference to Indian Geology); Structural Geology; Field geology ; Interpretation of maps.	Economic Geology* (*a*) Petroleum Geology & Sedimentary Petrology* ; (*b*) Ore Deposits.	
Mathematics . .	Descriptive geometry and Engineering Drawing ; Surveying. A Review course in Calculus. A Review course in Analytical Geometry.	Advanced Calculus ; Differential equations ; Vector analysis ; Elements of Potential Theory.		
Physics . . .	A Review course in Physics ; Mathematical theory of A.C. and Electrical measurements ; Elements of Radio and Electronics ; Photography.	Radio and Electronics (continued) ; Physics of the Earth ; Force Fields of the earth (*a*)Gravity, (*b*) Elasticity and Elastic waves, (*c*) GeoMagnetism, (*d*) Geo-Electricity and (*e*) Electromagnetic fields.		
Geophysics . . .	....	Introduction to Geophysical methods ; Magnetic Prospecting.	(*a*) Gravitation methods of prospecting ; Well-logging ; (*b*) Electrical Prospecting ; Seismic and Acousting Methods of Prospecting.	One of (*a*) Gravitation methods of prospecting and (*b*) Electrical prospecting. Radio-active prospecting; Geothermal Investigations ; Research in Geophysics.

*(*a*) Will be taken up by those intending to qualify as 'Petroleum Geophysicist.'
(*b*) Will be taken up by those intending to qualify as 'Mining and Engineering Geophysicist.'

Mineralogy.—Description, occurrence, association and uses of about 200 of the more important minerals ; elements of crystallography and practice and application of polarised light to the study of crystalline minerals ; miscroscopy in mineral analysis.

Petrology.—Laboratory.—Blow pipe analysis ; analysis of minerals by physical properties, chemical reagents and the blow-pipe. Origin of the three major rock types—igneous, metamorphic, and sedimentary ; physico-chemical principles involved in crystallisation of magma and the equilibrium concept as applied to metamorphic rocks ; special emphasis on typical structures, textures, and mineral associations.

Laboratory work.—Megascopic classifications of representative rock types from individual collections. Three independent field trips.

Historical Geology. (*Stratigraphy*).—A study of earth's history ; origin and significance of fossils ; methods of co-relation and the changes in relation of land to sea during the various geological periods ; the character and distribution of the deposits, the oregenic movements ; the igneous activity ; the life and the economic products of each geological period.

Second Year.

Historical Geology—(with special ref. to Indian Geology).

Elements of Paleontology.—Classification of the plants and the animal kingdom ; composition of the hard parts of organisms ; fossils and their modes of preservation ; basis of the present system of nomenclature and the rules governing the system ; characteristic structures, ecology and geologic history of the various phyla of invertebrate animals and plants.

Structural Geology.—Architecture of the earth with particular reference to the major forces causing deformation of the earth's crust ; study of primary and secondary rock structures such as are important in mining ; petroleum production and engineering operations : special reference to structurally important regions of India.

Laboratory.—Dip and strike problems, vein, intersections, convergence maps, and cross-sections ; a brief study of aerial photography in geological mapping. Two field trips.

Field Geology.—The following is included : Stratigraphic, structural, petroleum, igneous, metamorphic, and mining geology. Field work in these subjects includes : Study and mapping of a well-defined, faulted anticline and the consideration of its value as a potential oil field ; a study of petrology and paleontology of a thick series of sediments ; familiarisation with drilling operations ; study and mapping of igneous and metamorphic rocks, ore deposits and fault systems in well known mining districts in India.

Interpretation of Maps.

सत्यमेव जयते

Third Year.

Economic Geology.—A study of industrial minerals and rocks and of the metalliferous deposits of economic importance, with special emphasis on those occurring in India. Study of typical structural and petrologic relationships of each of the deposits as illustrated by detailed description of representative districts.

Ore Deposits.—(To be taken by those intending to specialise in mining geophysics.)

Laboratory study of representative specimens and of geological maps and of reports on typical mining districts. Study of each mineral product through the statistics of production and price changes against the background of world conditions.

Nature, origins and occurrence of ore deposits ; criteria useful in the recognition of the various types of ore deposits ; discussion of the changes in the character of ores with depth and mineral associations and alterations ; discussion of any other features likely to be of use in the examination of mining prospects.

Petroleum Geology.—(To be taken by students intending to specialise in petroleum geology.)

Chemical and physical properties of petroleum ; theories of origins and accumulation of petroleum and natural gas ; the reservoir rocks ; the types of oil and gas structures ; geology of the petroliferous districts of India and of some notable oil producing countries of the world.

Sedimentary.—(For petroleum geophysicists.)

Petrology.—A study of the characteristics of sedimentary rocks. Examination and correlation of samples taken from wells drilled by standard, rotary and core-drill methods ; screen analysis ; purity determinations ; grain size measurements.

(b) MATHEMATICS.

First Year.

Descriptive Geometry and Engineering Drawing.—Instruction in the use of drawing instruments; the basic principles of freehand lettering, certain essential mechanical alphabets; mechanical drawing of simple objects; various applications of the subject.

Technical sketching and isometrics; problems relative to the point, right line, and plane; generation of lines and surfaces; practice in the solution of underground mining problems involving faults, intersection of veins, etc.; construction of stereograms; tangent problems and problems involving the intersections and development of surface.

A Review Course in Calculus.—A review of Calculus with special emphasis on theory of single and multiple integration as applied to the principal methods of rectification and the calculations of surface, volume and of solids of revolution; solutions of numerous problems in areas, volumes, centroids and moments of inertia. Simple cases of differential equations.

A Review Course in Analytical Geometry.

Surveying.

Second Year.

Advanced Calculus.—Power series; partial differentiation, implicit functions; the definite integral; gamma, beta, Bessel and elliptic functions; line, surface and space integrals. A study of solid analytical geometry and the diff. geo. of space.

Differential Equations.—Ordinary differential equations with applications to physics, geophysics and engineering problems; theory and application of partial differential equations to the solution of physical questions such as free and forced oscillations in mechanical and electrical systems, heat flow, etc.

Vector Analysis.—An introduction to the algebra and calculus of vectors and their various scientific and engineering applications.

Elements of Potential Theory.—The theory of Newtonian potential functions and the concept of a physical field; discussion and development of the theorems of Gauss, Green and Stokes and their application to geophysics.

(c) PHYSICS.

First Year.

A Review Course of Physics.—Heat; Light; Electricity and Magnetism; General properties of matter with special emphasis on the principles of Electricity and Magnetism as applied to Geophysics.

Photographic Methods.

Mathematical Theory of Alternating Currents and Measurements.—Elements of A. C. Circuits; properties of resistance, capacitance and inductance, combination of these, and relation of volt and current; power factor.

Oscillatory circuits: resonance, frequence; impedance and phase relation; series and parallel resonance circuits; measurements of elements of A. C. Circuits: (*a*) Bridge methods; (*b*) Resonance methods.

Coupled Circuits: elementary theory; conditions of maximum power transfer; some special networks (*a*) resistance attenuators, (*b*) theory of filters.

Elements of Radio and Electronics.—Thermionic emission; theory of vacuum tubes of different types; diodes, triodes and multi-electrode valves; the cathode ray oscillographs and their uses.

Second Year.

Elements of Radio and Electronics.—Valves as amplifiers, detectors and oscillators; I. F. amplifiers of different types and their characteristics; design of typical amplifiers; measurements of gains and frequency response of an amplifier.

Audio and radio frequency oscillators; valve maintained tuning forks and piezo electric oscillators;

The elementary ideas of propagation of e.m. waves in space and through lines.

Simple electro-acoustic devices and their theory.

Physics of the Earth.—I. Physical Aspects of the various cosmological hypotheses and of paleogeography and paleoclimatology;

II. Description of the constitution and dynamics of the atmosphere and discussion of topics such as meteorology, atmospheric electricity, propagation of sound etc.

III. Constitution and dynamics of the hydrosphere, *i.e.*, hydrology and oceanography.

IV. Constitution and dynamics of the lithosphere; principles of seismology;

V. Force-fields of the Earth:—

(*a*) Gravity,

(*b*) Electricity and Elastic waves,

(*c*) Geomagnetism,

(*d*) Geo-electricity and

(*e*) Electro-magnetic fields.

(*d*) GEOPHYSICS.

Second Year.

Introduction to Geophysics.—The introductory course proposes to acquaint the students with the purpose and fundamental principles of applied geophysics so as to enable them to select the type of geophysical method for a given geological area.

Theoretical.—A discussion of the fundamental principles underlying all geophysical methods: classification; description of seismic, gravitational, magnetic and electrical methods of prospecting. In each of the four major heads, following should receive particular consideration (*a*); Properties of rocks and formations and methods of determination; (*b*) elementary theory and physical principles of instruments; (*c*) field technique; (*d*) corrections; (*e*) typical examples of application to geologic and economic problems; (*f*) elementary discussion of effects measured; *g*) interpretation of methods.

Magnetic Prospecting.—Fundamental principles; historical review; fields of application of the magnetic methods.

Magnetic properties of rocks and minerals; determination of susceptibilities residual magnetism and coercive force; factors affecting magnetisations of rocks.

Theory and description of geo-magnetic measuring instruments; Schmidt magnetometers, Hotchkiss Superdip; Swedish instruments and other prospecting magnetometers; regional survey instruments; observatory instruments.

Corrections for temperature, diurnal corrections, magnetic variations, planetary effects, base variation and eterrain effects; repeat observations.

Graphical representation of results; qualitative and quantitative interpretation; pull and line theory; induction theory; model experiments; underground, aerial and platform surveys;

Discussion of results of magnetic surveys in mining oil exploration.

Laboratory.—Experiments with Schmidt type magnetometers, dip needles and earth inductor; Determination of scale values, magnetic moments and temperature coefficients of Schmidt magnetometers and of magnets; demonstrations of magnetic variation-recording instruments; determination of magnetic properties of rocks.

Field work.—Regular week-end trips to localities where pronounced magnetic anomalies on a number of proved geological structures are already well known. Students will be required to carry a mgnetometric survey and measurements over oil bearing structures as also over those associated with mineral deposits, such as magnetic dikes and igneous formations.

Third Year.

GRAVITATIONAL METHODS OF PROSPECTING.

Theoretical.—Range of application of the gravity methods; historical review; densities of minerals, rocks and formations, and their determination; determination of the gravitational constant; the gravity compensator and the gravity multiplicator.

Gravity measuring instruments,—theory and operation; pendulums and gravimeters; theory of motion on firm and moving supports; instrumental corrections; corrections for topography; Bouguer reduction; transmission and reception of radio-time signals; analytical and graphical methods for the determination of two and three dimensional effects ; demonstration of results as related to geology.

Torsion Balance.—General features of the gravitational field ; geometry of equipotential surface of gravity ; theory of single curvature, single gradient, double gradient, and curvature variometer ; horizontal and vertical gradiometer. Types of instruments ; determinations of constants ; correction for normal, regional and terrain effects ; calculation and graphical representations of results ; theory of two and three dimensional effects ; analytical, graphical and planimeter methods, qualitative and quantitative interpretation ; relation of gravitational and magnetic anomalies.

Laboratory.—Operation and calibration of gravimeters ; operation of Schweydar Z-type torsion balance ; computation of instrumental constants ; changing wire and adjustment of instrument ; recording in three, four and five positions ; computation of the results ; terrain measurements and instructions in terrain corrections, measurements of densities.

Field work.—A field programme of about two weeks for gravitational survey with pendulums gravimeters, and torsion balance, on a pronounced oilbearing structure ; comparison with magnetometer results in the same structure.

ELECTRICAL PROSPECTING.

Theoretical.—Application of electrical methods ; history of electrical prospecting ; classification ; electrical properties of rocks ; electro-chemical effects ; metallic and electrolytic conduction ; determination of resistivity and dielectric constants ; their values for ores, rocks and formations.

Self-potential method ; equipment, theory, interpretation, result ; self-potential of ore bodies and its determination.

A. C. and D. C. equipotential line and potential profile methods ; equipment, procedure, effect of geologic bodies ; effects of stratified ground ; model experiments ; results.

Resistivity methods : theory of images ; procedure, equipment and interpretation, results ; electrical logging.

Potential drop-ratio and other potential methods.

Electromagnetic methods (*a*) with galvanic power supply and (*b*) with inductive power supply ; influence of polarisation of the field, of phase shift, of leads, of topography and of frequency ; theory of subterraneous effects ; vertical and horizontal loops, and their application in mining geology ; influence of magnetic permeability.

Radio-methods : absorption and reflection of radio waves ; changes in capacity or self-induction of radio circuits by buried conductive bodies.

Laboratory.—Determination of resistivities of rocks at different frequencies ; measurement of contact resistance of electrodes for A. C. and D. C. ; model experiments with the Gish-Rooney and Racom method ; shape of the normal electrical field and tank experiments with point or linear electrodes ; measurement of equipotential lines, of potential profiles and of the electromagnetic field components ; tank experiments with model ore bodies ; determination of their effects on the A. C. and D. C. equipotential, electromagnetic and inductive methods.

Field Work.—Measurements with the self-potential resistivity, A. C. potential, electromagnetic, and inductive methods to be undertaken as a known ore body in a neighbouring mining district. Determination of the thickness of basalt sheets and location of ground water tables. Structural studies with potential and inductive methods.

SEISMIC METHODS OF PROSPECTING.

Historical Review : *Applications.*—Theory of elastic deformations and wave propagation elastic properties of rocks ; speed of works, absorptions, specific acoustic resistance.

Geophones, microphones and other listening devices ; determination of sound intensity and direction ; selected topics of seismology such as relation of macroseismics and geology ; trave time curve for the earth, etc.

Seismographs.—Theory and description of seismographs ; classification ; general theory of free and forced, damped and undamped oscillations ; the mechanical seismograph ; the electro magnetic seismograph ; description of station in seismographs ; vibrographs, prospecting seismographs ; photographic recording and time marking methods ; seismograph calibration.

Methods of Seismic Prospecting : source of energy, energy transmission, periods, transmission of shot instant ; fan shooting method ; refraction and reflection methods ; theory of seismic propagation path ; practice of interpretation ; results of statistics.

Laboratory.—Determination of physical constants of mechanical and electrical seismographs: action of seismographs action of seismographs : on a shaking table ; measurements of elastic moduli of rocks ; work with the standard geophone.

Field Work.—Field practice with various types of seismographs on week-ends, experience with radio and wire transmission, velocity determinations in various formations ; tests with geophones ; comparison of seismic data with magnetometer and torsion balance results.

Fourth Year. (Post-graduate).

Radio-Active Prospecting.—Fundamental principles of radio-activity ; elements of atomic theory and nuclear physics ; radio-active transformations and radiations ; instruments and methods used for measuring radio-activity of minerals ; methods of radio-active prospecting ; analysis and interpretation of results.

Laboratory.—Determination of radio-activity of minerals.

Field Work.—Measurement of radio-activity on radio-active veins and fissures.

Geothermal Investigations.—The thermal gradient ; its cause and relation to the internal heat of the earth ; effect of conductivity of rocks, volcanic processes, water circulation, chemical reactions and physical factors on the gradient ; influence of surface temperatures and surface reliefs ; instruments and their use in geothermal investigations ; application of the methods, results and interpretations.

Research in any one of the following :—

Magnetic,
Gravimetric,
Electrical,
Seismic,
Radio-active,
Geothermal Methods of Prospecting.

(iv). *LABORATORY EQUIPMENT.*

I. DIVISION OF GEOPHYSICS PROSPECTING.

Magnetic Laboratory.—Vertical Schmidt magnetometers or Askania types ; Horizontal Schmidt magnetometers or Askania types ; Equipment for determining Scale values and magnetic moments; Heating apparatus for magnetometers ; Askania-Rotary inclinator with Zeiss Loop Galvanometer ; Astatic magnetometer for automatic recording of temperature coefficients of magnets ; Deflection magnetometer for determination of magnetic properties of rocks ; Equipment for photographic recording of magnetic daily variations.

Gravitation Prospecting Laboratory.

Askania Gravimeter (by Graf).

(measures gravity diff. to 0·1 mg. and has a range of 1,600 mg., over which the scale is linear).

Frost Gravimeter.

Beam type of torsion balance (American Askania Co.) ;

Equipment for terrain correction ; Instruments for the treatment and standardisation of torsion wires.

Electrical Prospecting Laboratory.

Gish-Rooney Four Terminal outfits with commutators ;
Racom Outfit ;
Potentiometers and milliammeters ;
Self Potential Equipment ;
Gasoline engine ;
500 cycle A. C. Generator ;
Buzzer generator ;

Apparatus for the determination of resistivity of rocks at various frequencies ;
Equipment for equipotential line method ;
Equipment for electromagnetic and inductive methods ;
Concrete tank for model experiments.

Seismic Prospecting Laboratory.

Schweydar mechanical two-component seismographs with recorders ;
Composite radio transmitters and receivers ;
Blasting equipment ;
Standard sets of geophones ;
Push-pull recording geophones ;
Electrodynamic seismographs.

Radio-Active Laboratory.

Ambronn Emanometer ;
Laboratory equipment for radio-active tests ;
Beta-Ray Spectrograph.

Geothermal Prospecting Laboratory.

One deep well temperature machine, U. S. G. S. pattern.

II. DIVISION OF PHYSICS.

Radio and Electronics Laboratory.—

Alternating Current :—

1. A. C. Impedance Bridge with accessories ;
2. Calibrated radio frequency oscillator ;
3. Calibrated audio (beat frequency) oscillator.
4. L. F. Attenuator ;
5. Thermionic Valve Voltmeter ;
6. D. C. and A. C. Meters ;
7. Calibrated variable air condensers ;
8. Assorted Valves and components.

General Physics and Electrical Laboratory.

Photographic Laboratory.

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III. DIVISION OF GEOLOGY.

Geological Laboratory.

COSTS.

Within the limited time at disposal and also owing to postal strike and the abnormal situation in Calcutta, it has not been possible to work out in full details the cost of equipping the various laboratories to be set up under the Institute so far as geophysical laboratories are concerned. The foregoing list of apparatus has been prepared on the basis of the Geophysical Department of the Colorado School of Mines, Golden, Denvar. The geophysical equipment of that Department, it is reported in one of the quarterly issues of the School of Mines, represents an investment of 25,000 dollars or about Rs. 1,00,000. This Department was, however, built in 1926. Owing to inflation and increased price of scientific instruments, to which should be added import duties, the cost of equipping the laboratories for teaching and research in geophysics may amount to Rs. 2,50,000. Another sum of Rs. 1,50,000 will be necessary for equipping general physics, radio and electronics and geological laboratories and also an up-to-date machine shop, capable of undertaking repair work and manufacture, to a certain extent, of common instruments for geophysical exploration. This will, therefore, involve a capital expenditure of Rs. 4 lakhs approximately towards laboratory equipments.

(v) *STAFF REQUIREMENTS*

	Director (An eminent geophysicist).	1
	Personal Assistant to Director	1
I. Division of Physics	Professor of Physics	1
	Lecturer in Physics (One specialising in Radio and Electronics).	2
	Scientific Instructors	2
II. Division of Mathematics	Professor	1
	Lecturers	2
	Instructor (specialising in Engineering drawing)	1
III. Division of Geology	Professors (one should be Professor of Mineralogical Chemistry)	2
	Lecturers	2
	Field Geologists (Lecturer's grade)	2
	Scientific Instructors	2
IV. Division of Geophysics	Professors (one should be a specialist in Seismology)	2
	Lecturers	4
	Scientific Instructors	4
	Research Staff in Geophysics—	
	Senior Scientific Officers	4
	Junior Scientific Officers	6
	Scientific Assistants	8
	Research Scholars	(a good number)
V. Machine Shop	Foreman and Chief	1
	Instrument Maker	2
	Senior Mechanic	1
	Electrician	2
	Draftsman—Designer	1
	Draftsman—Lithographer	1
	Mechanics	4
VI. Library and Intelligence	Librarian	1
	Assistant Librarian	1
	Clerks	4
	Statistician	1
	Editor of Publications	1
VII. Ministerial	Office Superintendent	1
	Accountant	1
	Senior Clerks	2
	Junior Clerks	4
	Stenographers and Typists	5
	Menial Staff (Peons, Orderlies, Laboratory-bearers, porters, watchmen, sweepers, etc.).	15
	Total personnel	89

(vi) *SALARY OF STAFF*

Post	No.	Grade. Rs.
Director	1	1,500—100—2,000
Professor	6	800—25—850—35—1,250
Lecturer	10	350—25—550—30—700
Field Geologist	2	350—25—550—30—700
Senior Scientific Officer	4	350—25—550—30—700
Junior Scientific Officer	6	250—25—500
Scientific Assistant	8	150—20—450
Scientific Instructors	9	150—20—450
Foreman	1	350—25—550—30—700
Instrument Maker	2	250—25—500
Senior Mechanic	1	125—15—350
Electrician	1	125—15—350
Draftsman	2	125—15—350
Mechanic	4	60—5—90
Librarian	1	350—25—550—30—700
Assistant Librarian	1	150—20—450
Office Superintendent	1	250—25—500
Accountant	1	150—20—450
Editor of Publications	1	350—25—550—30—700
Statistician	1	250—25—500
Senior Clerk	2	125—5—180—10—300
Junior Clerk	8	100—5—175
Stenographer	2	125—5—180—10—300
Typist	3	100—5—175
Menial Staff	15	20—1—35

Research Scholarships—

Senior	Rs. 250
Junior	Rs. 150

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(vii) *HOUSING REQUIREMENTS.*

A. Director's Office and the Administrative Block—

	Square feet.
Director's Room	20×20= 400
Conference Room	25×20= 500
Personal Assistant	20×10= 200
Office Superintendent	15×10= 150
Accountant	15×10= 300
General Office (for clerks, stenographers, typists, etc.)	20×50=1,000
Visitors Waiting Room	20×15= 300
	2,850

B Library and Intelligence—

Librarian's room	20×10= 200
Assistant Librarian	15×10= 150
Editor of Publications	20×10= 200
Statistician	20×10= 200
Office	20×20= 400
Reading Room	25×20= 500
Stock Room	1,000
	2,650

C. Lecture Rooms—

	Square feet.
Lecture Rooms (5)	5×25×20=2,500
Conference Room	50×20=1,000
Students Common Room	25×20= 500
	4,000

D. Machine Shop—

Foreman's Room	20×10= 200
Instrument-Maker's Room	25×20= 500
Drawing Room	25×20= 500
Workshop Tools Room	50×20=1,000
Glass Blowing Room	20×20= 400
Stores Rooms (2)	2×25×20=1,000
Central Power Supply Room	1,400
	5,000

E. Division of Geophysics—

Professors' Rooms' (2)	2×20×15= 600
Lecturers' Rooms (4)	4×15×10= 600
Senior Scientific Officers' Rooms (4)	4×15×10= 600
Magnetic Laboratory	25×20= 500
Electrical Laboratories (2)	2×25×20=1,000
Model Tank Experiment Laboratory	25×20= 500
Gravitational Laboratory	25×20= 500
Dark Room	15×10= 150
Constant Temperature Room	15×10= 150
Seismic Laboratories (2)	2×25×20=1,000
Completely shielded recording and screen rooms (2)	2×20×20= 800
Dark Room	15×10= 150
Radio-Active Laboratory	25×20= 500
Geothermal Laboratory	25×20= 500
Rock testing Laboratory	25×20= 500
	8,050

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F. Divison of Physics—

Professor's Room	20×15= 300
Lecturers' Rooms (2)	2×15×10= 300
General Laboratory	25×20= 500
General Electric Laboratory	25×20= 500
Radio and Electronics Laboratories (2)	2×25×20=1,000
Photographic Laboratory	25×20=500
	3,100

G. Division of Geology—

Professors' Rooms (2)	2×20×15= 600
Lecturers' Rooms (3)	3×15×10= 450
Geological Laboratories (3)	3×25×20=1,500
Laboratories of the Mineralogical Chemist (2)	2×25×20=1,000
	3,550

H. Division of Mathematics—

	Square feet.	
Professor's Room	20×15=	300
Lecturers' Rooms (2)	2×15×10=	300
Engineering Drawing Room	25×20=	500
		1,100

Miscellaneous—

Garage for housing trucks (4) fitted with gravimeters and seismic instruments, etc.	4×300=	1,200
Restaurants	2×400=	800
		2,000

Total Requirements—

	Square feet.
Block A.	2,850
,, B.	2,650
,, C.	4,000
,, D.	5,000
,, E.	8,050
,, F.	3,100
,, G.	3,550
,, H.	1,100
,, Miscellaneous	2,000
TOTAL	32,300

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MGIPC—M—XI-1-59—29-4-48—600.

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Mean annual changes of declination plotted against time. Chart 1

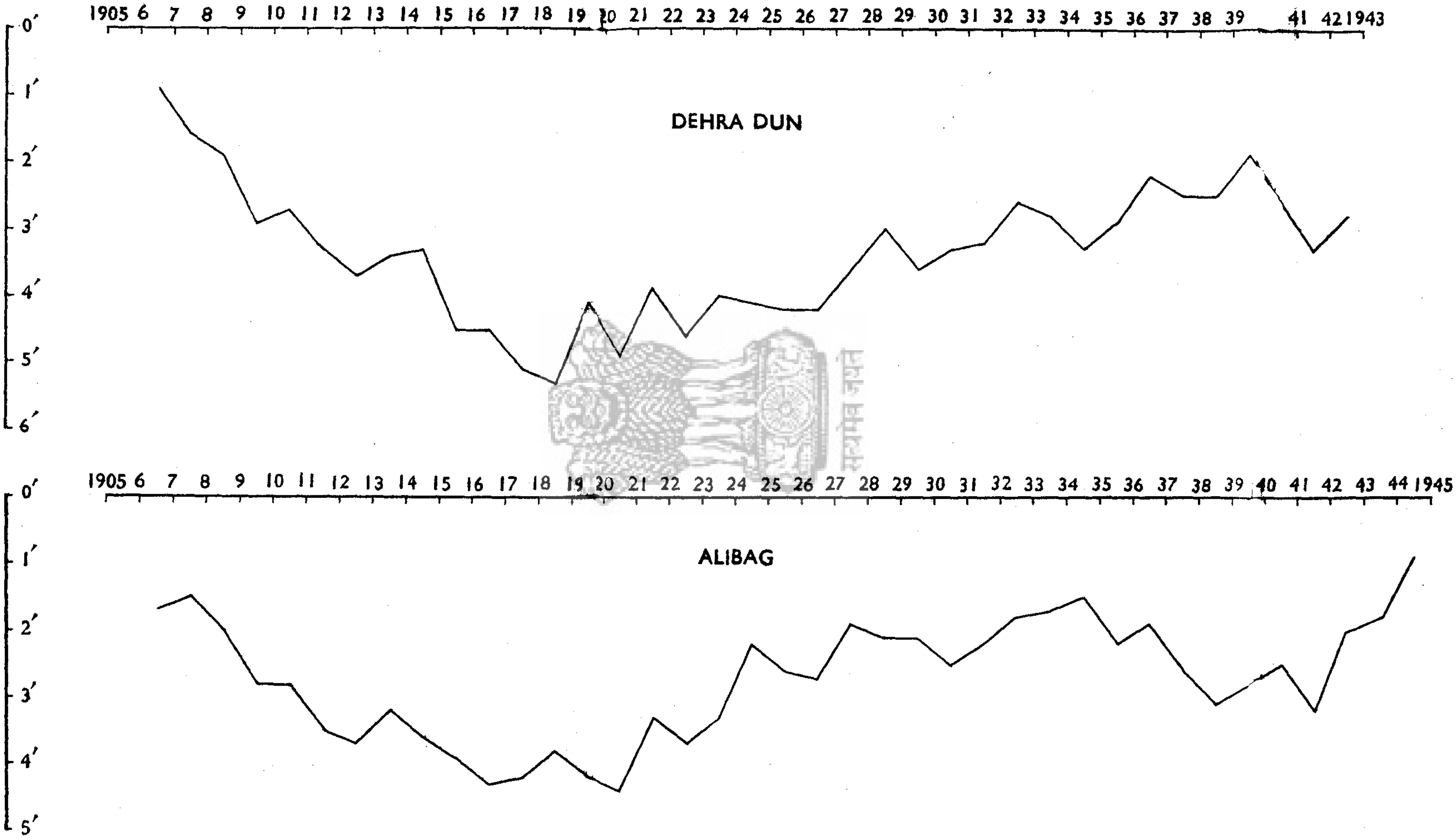

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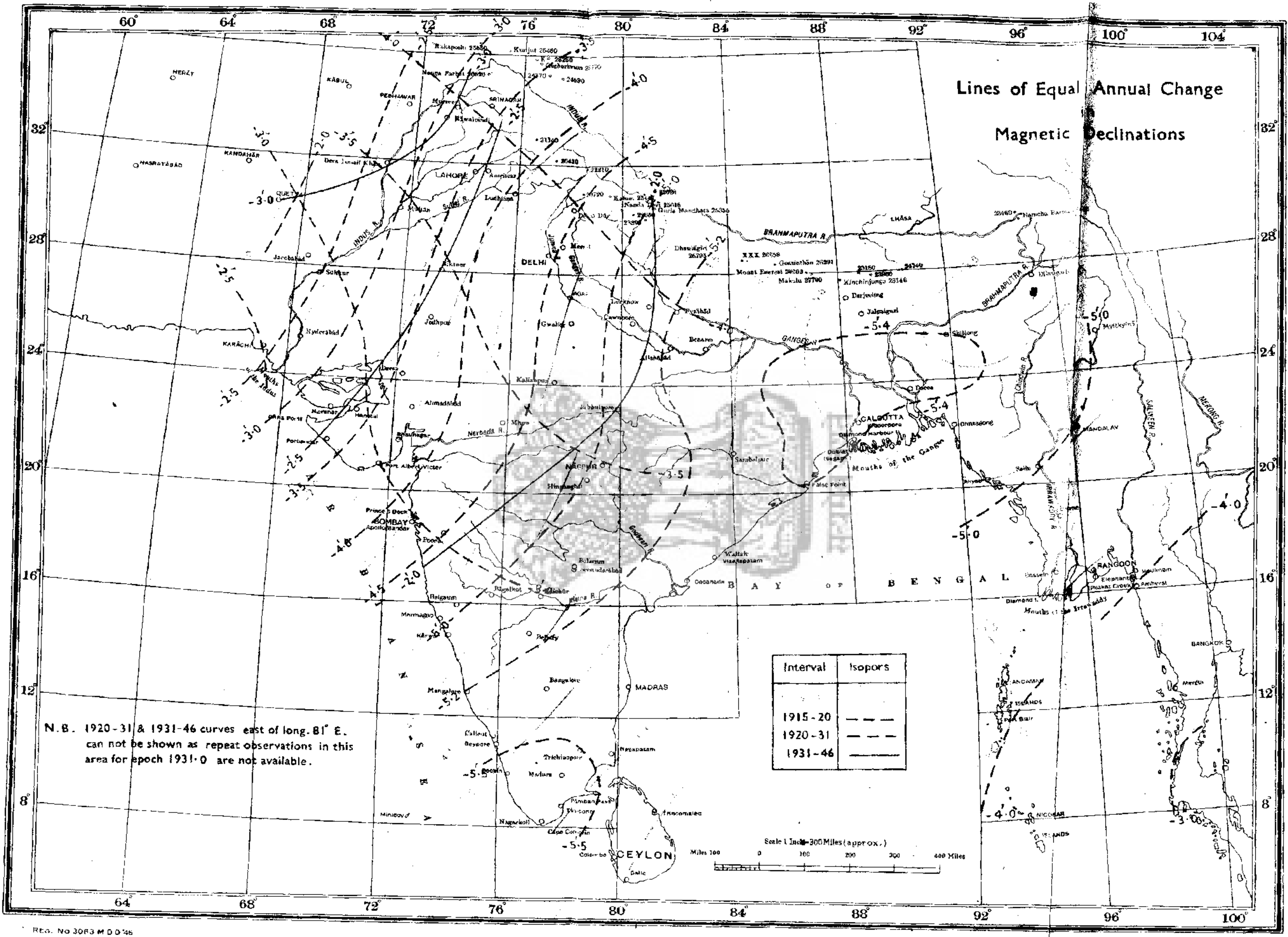
Chart II

Lines of Equal Annual Change in Magnetic Declinations



N.B. 1920-31 & 1931-46 curves east of long. 81° E. can not be shown as repeat observations in this area for epoch 1931·0 are not available.

Interval	Isopors
1915-20	— — —
1920-31	— —
1931-46	———

Scale 1 Inch=300 Miles (approx.)

Miles 100 0 100 200 300 400 Miles

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